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Virtual Memory Palaces: The Impact of Design on the Memorization Performance

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"Science, like all creative activity, is exploration, gambling, and adventure. It does not lend itself very well to neat blueprints, detailed roadmaps, and central planning. Perhaps that's why its fun."

Herbert Alexander Simon

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List of Acronyms

Approx.	Approximately
AR	Augmented Reality
CAVE	Cave Automatic Virtual Environment
Covid-19	Coronavirus Disease 2019
DREPT	Design-relevant Explanatory/Predictive Theory
DSR	Design Science Research
DSRM	Design Science Research Methodology
DT	Design Theory
e.g.	exempli gratia (for example)
fMRI	functional Magnetic Resonance Imaging
HMD	Head-Mounted Display
i.e.	id est (that means)
IS	Information System
LTM	Long-term Memory
MOL	Method of Loci
PC	Personal Computer
PDA	Personal Digital Assistant
STM	Short-term Memory
TV	Television
VCP	Virtual Capability Palace
VE	Virtual Environment
VMP	Virtual Memory Palace
VR	Virtual Reality

Zusammenfassung

Diese Arbeit widmet sich der Untersuchung einer innovativen Lern-Software, die moderne Technologie mit einer antiken Lernmethode verknüpft. Die Einleitung beschreibt in Kürze die aktuelle Situation zum Thema Bildung in der digitalen Transformation und erklärt wie eine antike Mnemotechnik, die Loci-Methode (oder auch „Gedächtnispalast"), in der aktuellen Forschung wiederbelebt wird. In der traditionellen Variante muss man sich eine gewohnte Umgebung vorstellen, die dann als Gedächtnispalast dient. Die Lerninhalte werden in diesem Gedächtnispalast entlang einer Route mit ungewöhnlichen Bildern eingeprägt. Dieser Vorgang wird wiederholt, bis man in der Lage ist seinen Gedächtnispalast in Gedanken erneut abzulaufen, und die Inhalte „abzuholen". Die softwaregestützte Variante der Loci-Methode nennt sich „virtueller Gedächtnispalast". Hierbei erfolgt das Training nicht mehr in Gedanken, sondern mithilfe einer virtuellen Umgebung, zum Beispiel an einem Computer Bildschirm. Nach der Einleitung folgen theoretische Grundlagen zu den Themen Lernen, der Loci-Methode und dem Aspekt Design. Daraufhin wird eine strukturierte Literaturanalyse beschrieben, die in der Forschungsfrage mündet, ob das Design eines virtuellen Gedächtnispalastes einen Einfluss auf die Erinnerungsleistung hat. Danach wird eine passende Forschungsmethodik evaluiert. Die Argumentation leitet eine gestaltungsorientierte Herangehensweise her, die dazu dient ein Forschungsmodell mit mehreren Zyklen und drei identifizierten gestaltungsrelevanten Bereichen zu untersuchen. Die Ergebnisse der Untersuchungen zeigen, dass die Gestaltung eines virtuellen Gedächtnispalastes tatsächlich signifikanten Einfluss auf die Erinnerungsleistung hat. Daraus folgende Implikationen, Hinweise für zukünftige Forschungsvorhaben in diesem Thema, als auch eine allgemeine Schlussfolgerung werden im letzten Kapitel beschrieben.

Preface

I started my doctoral career at the end of 2013. I thought: "Wouldn't it be cool if you could boost your memory with the help of a virtual environment?" I read a few, relevant publications, and said to myself: "Great. They're already doing that." But then I realized how much more potential there was from a researcher's perspective. Along the way, I experienced some significant events worth mentioning. The most important one was when Susanne agreed to support this research endeavor. I want to thank her for letting me work on that topic, for valuable feedback and critics along the way. Thank you for the good time we had, and everything I learned from you, and in this job in the last seven years. I want to thank my colleagues for inspiring research talks, the laughs, the parties, and volunteering as guinea pigs in the pre-tests of my experiments. Two unexpected events were quite motivating for me and my research. The first one was when Carsten Brinch Larsen wrote me an e-mail and suggested to talk about my research and his business. He founded "MemorixDK" together with Hermann Kudlich. These guys are developing a virtual memory palace for commercial purposes. We had exciting talks, among others, about practical issues, which were quite insightful for me as a researcher. The second event happened in Berlin. I got invited by Martin Dresler to speak at the "Symposium Ars Memoriae" in November 2018. Me coming from the field of information systems, it was fascinating and inspiring to listen to and discuss with neuroscientists, psychologists, and a memory artist about mnemonics and the method of loci.

Last but not least, I want to thank my fiancee Maike for her love, support, and patience over recent years. She was always encouraging and supportive.

1 Introduction

Education is and has always been an essential factor for individuals and society to achieve and maintain prosperity. It was shown, and it is intuitively true that communities profit substantially from educated people (Hanushek and Woessmann, 2008; Jones and Vollrath, 2002; Rindermann, 2008; Varadarajan Sowmya et al., 2010; Wößmann, 2017). Especially in the last 30 years, modern technology played a growing role in education; hence, for teachers and learners (Scott, 1995). Along with the "Digital Transformation", which stands for the multi-layered change that came with a plethora of new technologies, the internet was quickly identified as a promising technology for the educational domain (Agarwal and Day, 1998; Le and Stein, 2001; Marriott et al., 2004; Peterson and Facemyer, 1996; Petko et al., 2018). Until today, this source of information grew not only in its size of data but also in the relevance for a chance of succeeding at ones learning goals (Sursock and European University Association (EUA) (Belgium), 2015). Moreover, devices like laptops, smartphones, tablet PCs, or even head-mounted displays combined with enhanced communication and media presentation forms offer optimized scenarios for teachers and learners. In this dissertation, the research focuses on an innovative concept that combines modern technology with an ancient learning strategy.

Motivation & Relevance

While each learning process' goal is to develop higher-order thinking capabilities, the first hurdle to be taken is to memorize crucial information like specific terms, facts, or values (Bloom et al., 1956). The amount of information students have to memorize along their career varies depending on the type of schools, classes and subjects. However, it can become quite extensive in higher education like biology, law, or medicine (Qureshi et al., 2014). Besides others, a possible solution for this challenge might be well studied, but poorly established learning strategies: mnemonics. A detailed description of mnemonics follows in chapter 2. In short, these are learning techniques that suggest to mentally associate (e.g., with vivid imagery) learning content with normally unrelated objects to facilitate memorization. As shown by Putnam (2015), mnemonics are capable of increasing the students' motivation to learn by facilitating the memorization of information and being fun at the same time. Not only popular among memory artists (Maguire et al., 2003; Putnam, 2015), the mnemonic strategy called method of loci (MOL, also called memory palace) is the most powerful mnemonic to remember an extensive amount of information. For instance, in 2014, Simon Reinhard was able to memorize the correct order of 52 cards in under 27 seconds at a memory tournament (Putnam, 2015). Again, a deeper explanation follows in the later chapters but briefly described: The MOL is based on the idea to use a familiar environment as mental storage for information. One imagines placing the learning content in the environment in certain places. This has to be iterated several times. In order to recall, again, this environment has to be mentally traversed to pick up the information along the way. While the idea of broadly establishing mnemonic strategies in the students' curriculum is at least thirty years old (Levin and Levin, 1990), it has not been done yet (Putnam, 2015). Peeters and Segundo-Ortin (2019, p.2) explain this by the fact that, for instance, the MOL "[...] takes long-term practice, in a suitable environment, and requires creative imagination". Similar criticism was identified by Putnam (2015), who explained that besides the unquestioned potential that lies in mnemonic techniques, some researchers doubt their efficiency in an educational context due to the intense effort necessary for its application. This is one motivation, amongst others, why researchers began to modify the traditional MOL and support the use of it with the help of virtual environments, such as on a computer screen. So the basic idea is instead of using the own mind and a familiar environment, the user traverses through a virtual environment and memorizes it as a template for her or his memory palace. This concept will also be described in detail (section 2.3), and is referred to as Virtual Memory Palaces (VMP). However, while the studies that cover this idea date back to 1997 (Wong and Storkerson, 1997), an increased research effort only just began as to be shown in the upcoming literature review (chapter 3). This research aims to further investigate and contribute to the VMP concept by taking a closer look at fundamental questions and suggesting a design-related research methodology to motivate future work in this topic.

Structure

The next chapter intends to give the reader an introduction to relevant background knowledge for the addressed issues. Followed by a structured literature review which results in the general research question, the discussion then leads to a reflection on how research in this context should be conducted. This concludes with a research model built to address the identified research problem. Chapter 6 contains four published papers that collectively answer the research question and explain the belonging studies in detail. Finally, the results are summarized and discussed.

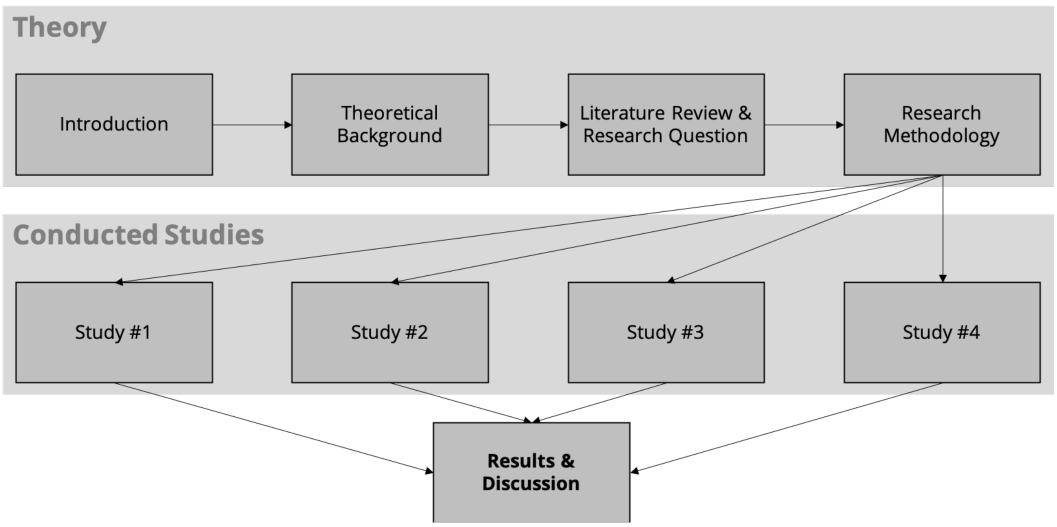


Figure 1.1: Structure of the Thesis

2 Theoretical Background

Starting with "Cognition & Learning", the first section provides an overview of how the learning process works according to the scientific community. The next section explains what mnemonics are, what (virtual) memory palaces are and how and why mnemonic learning strategies work so well. At last, the topic of design is described.

2.1 Cognition & Learning

Cognition and learning are both domains one can write books about. However, many researchers and educators tried to find out how learning actually works. As a result, models and paradigms of the process of cognition and learning emerged in the scientific community.

In the 1960s and 1970s, research focused on the question of how thinking and learning is actually created in the human's mind (Anderson, 2015). This focus defined a new field of research named cognitive psychology (or cognitivism), which emerged from behaviorism. Behaviourism was the first learning paradigm that grew in the research community. Here, the human memory is regarded as a black box that responds to a certain stimulus with a certain reaction (Güldenberg, 2001; Klusendick, 2007; Wentura and Frings, 2013). For the investigations in traditional cognitive psychology, the experimental approach was adopted from behaviorism. As a result, the first explanations for mental processes were developed (Anderson, 2015; Klusendick, 2007; Wentura and Frings, 2013). The focus of cognitive psychology is the study of human cognition. This encompasses all mental mechanisms of information processing from the first perception of an object to its integration into one's own thought and action pattern (Klusendick, 2007). At the end, a new insight and a new basis for decision-making emerges from this process (Eysenck and Keane, 2010). The basic cognitive processes are regarded as a prerequisite of human intelligence and are differently pronounced in each person (Anderson, 2015; Thurstone, 1938). The crucial constructs for explaining cognitive processes are perception, memory and information processing (Klusendick, 2007). Perception is understood as a process by which the individual gains knowledge of himself and his environment (Kroeber-Riel and Weinberg, 2003). Memory is defined as the ability to assimilate information, whereas information processing focuses on the organisation, the use of information and the adaptation of knowledge in the long-term memory (Klusendick, 2007). For a better understanding of how memory works, the "multi-store model" of Atkinson and Shiffrin (1968) shall be described briefly. It illustrates the process of how information is stored in the memory (see figure 2.1). In this model, the memory is further divided into three subsystems.

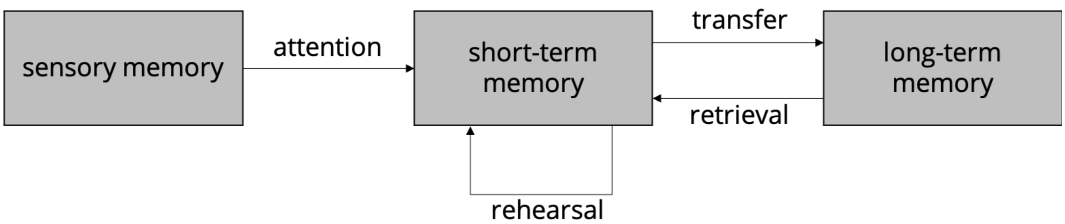


Figure 2.1: Multi-Store Model of Atkinson and Shiffrin (1968)

The information from the environment, which is taken up by the sensory organs, is kept completely present in the sensory memory for milliseconds. This memory consists of two channels of perception, one for the reception and storage of auditory stimuli and the other for the reception and storage of visual stimuli (Tindall-Ford et al., 1997). The right hemisphere of the brain processes predominantly visual elements (e.g. the visuospatial sketchpad) and the left hemisphere processes linguistic and auditory contents (e.g. the phonological loop, see figure 2.2) (Springer et al., 1998). Only the information to which one focuses on is passed on to the short-term memory (STM). The STM serves as a working memory, that further processes the information. It has a small capacity, which stores its content for about 15 to 45 seconds. To prevent the new information from being forgotten, it must be repeated. The more often the information is elaborated in the STM, the higher the probability that it will be transferred into the long-term memory (LTM). This memory has a high capacity, which is why it can store a lot of information permanently (Klusendick, 2007). Research suggests that the LTM is divided into two categories. Depending on the type of information, it is supposed to be stored in the non-declarative or the declarative memory. Figure 2.2 illustrates the breakdown of the LTM according to the traditional taxonomy of memory (Bird and Burgess, 2008). The complexity of the human memory process is quite high. So, an extensive explanation of all the mechanisms and theories about it is out of scope at that point. Hence, only the relevant aspects are briefly described.

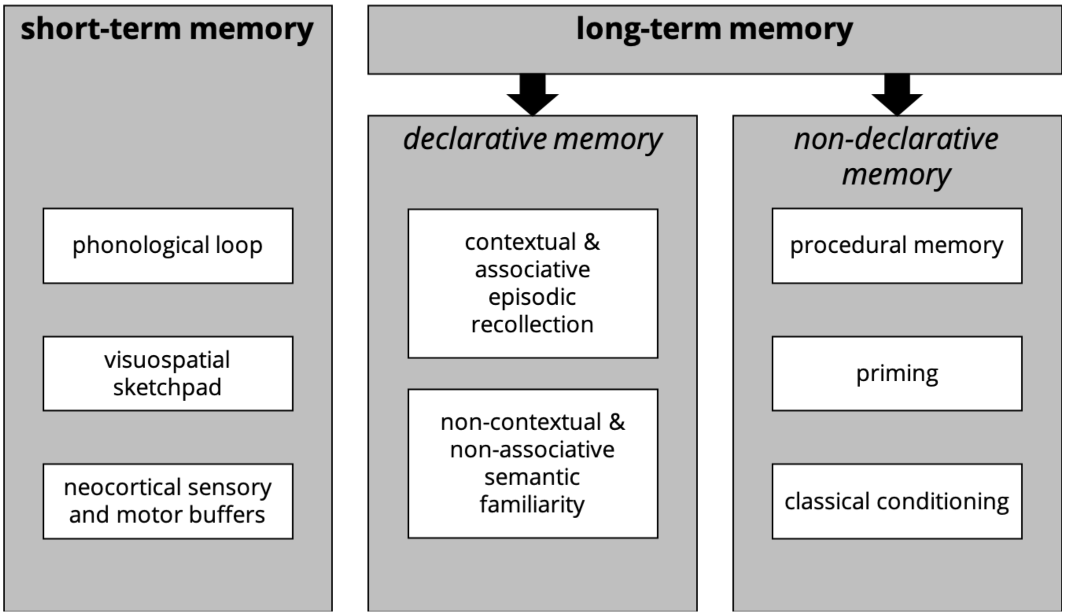


Figure 2.2: Taxonomy of Memory Systems by Bird and Burgess (2008)

The non-declarative memory contains automatic action sequences which are carried out without great cognitive effort and are acquired through implicit learning or unconscious learning. The declarative memory stores factual knowledge and experiences of the individual, which can be consciously reproduced. For instance, the episodic memory stores personally experienced events. Hence, the context of this memory is still available. In contrast, there is also declarative, factual knowledge which is not associated (anymore) with a particular context (the type of knowledge meant by "familiarity" or "semantic" in figure 2.2). Declarative knowledge is acquired through explicit or conscious learning. Accordingly, memory serves to process information in the brain and categorize it (Atkinson and Shiffrin, 1968; Holzinger, 2000; Klusendick, 2007; Mayer and Moreno, 2003; Wentura and Frings, 2013).

Güldenberg (2001) concludes that learning takes place in the memory, since it is the centre of information processing. One learns by linking old, already existing knowledge with new information or by linking old knowledge in a new way (ibid.). This kind of active information processing includes the possibility of changing attitudes and behaviour (Klusendick, 2007; Mayer and Moreno, 2003) and thus learning. The learning effect results from a cognitive dissonance[1]. Then, the current information status has to be reassessed and the mental representation has to be adapted (Gegenfurtner, 2006; Klusendick, 2007).

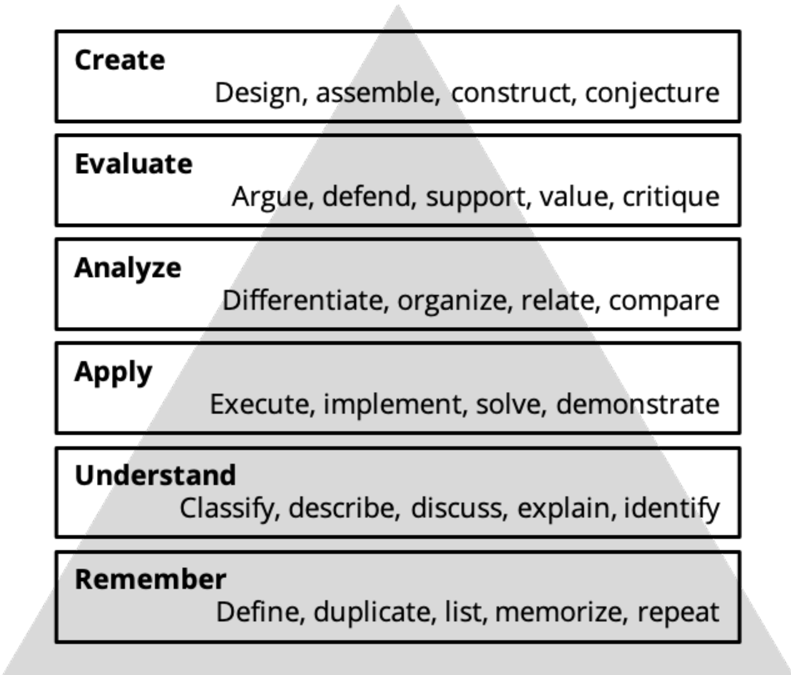


Figure 2.3: Bloom's Taxonomy, revised by Krathwohl (2002)

In summary, learning is a process. It starts from memorizing over acquiring knowledge towards developing certain skills. Based on Blooms taxonomy of learning, the two-dimensional framework of Krathwohl (2002) classifies learning content

[1]Cognitive dissonance is the result of at least two cognitions that conflict each other. This leads to inner tensions and the person changes their decisions to get back into a balanced state of mind (Festinger et al., 1978)

in terms of the structure of the knowledge dimensions and the level of the cognitive process at which the learning content is acquired (see figure 2.3). The complexity of learning increases with each additional level in the respective dimension. The first level of the knowledge dimension is factual knowledge. This comprises the basic elements that must be known in order to solve problems in a discipline. On the first level of the cognitive learning process is the remembering or retrieval of relevant knowledge from the long-term memory (ibid.). Consequently, the basis of learning is remembering existing knowledge and the basis for learning complex contexts is factual knowledge in the form of terminology and specific details.

2.2 Method of Loci & Memory Palaces

The MOL belongs to a set of learning strategies called mnemonics. Mnemonics are memory aids that support the memorization of information (Bellezza and Reddy, 1978). The basic idea of mnemonics is to transform any kind of learning content into easily imaginable things and then arrange, structure, and organize them. To do so, learners create mental associations between the learning content and an object (Yates, 1999). For this purpose, natural mechanisms of memory processing are used (cf. section 2.1) (Putnam, 2015). Mnemonic strategies use especially visual imagery to encode the learning content (Bellezza and Reddy, 1978; Roediger, 1980). Numerous studies have found a positive effect of mnemonics on human memory performance (Bower, 1970; Hartwig and Dunlosky, 2012; Mann et al., 2017; McCabe, 2015; Roediger, 1980). The research suggests using mnemonics in educational settings, since they may help students and thus promote successful completion (Hartwig and Dunlosky, 2012; McCabe, 2011). This is due to the positive influence of mnemonics on the learners LTM (Hagström and Winman, 2018; Putnam, 2015; Ralby et al., 2017; Wagner et al., 2020). Students who develop their mnemonics or stories on their own are particularly effective (Börner, 2001b). In general, the more effort the learner invests in defining meaning and how to remember it - the so-called "depth of processing" - the better she or he can remember it (Bobrow and Bower, 1969; Loucky, 2006). So, any kind of pictures, stories, word associations, or other mnemonic aids that a student actively uses will lead to an improvement in memory performance [Godwin-Jones 2010]. Furthermore, Putnam (2015) explained that there is a positive correlation between the students' motivation to learn and the use of mnemonic strategies. The idea of integrating mnemonics into the curriculum is not new and was already proposed in the 1990s (Levin and Levin, 1990).

However, there are also other domains in which mnemonics are used. For instance, many memory athletes use a mnemonic called memory palace. Here, the athletes have an extensive spatial and navigational knowledge of a mental environment that stores the relevant information (Godwin-Jones, 2010; Maguire et al., 2003). This allows them to focus on a specific element of their chosen environment with the help of complexity and spatial richness (Ng et al., 2010). The memory palace is one of the oldest mnemonics there are (Spence, 1985). Other synonyms for the MOL than memory palace are mind palace, or journey method (Foer, 2012). The concept is based on an ancient Greek mnemonic, which is approximately 2500 years old. Before printing was invented, the ability to memorize information was "vitally important" (Yates, 1999, p.xi). The central idea is attributed to the poet Simonides of Ceos. He was able to remember the guests' names at a dinner party after the roof collapsed, and the bodies were disfigured beyond recognition. Simonides used the spatial surroundings and the seating arrangement, to identify each corpse (Hedman and Bäckström, 2000; Yates, 1999). The MOL is a visual approach to storing and retrieving information. The idea is to mentally link a visual representation of the learning content to objects or places - the loci (Latin *locus* = place, plural *loci*). The loci are situated in a known environment - the memory palace - on a known route (Hedman and Bäckström, 2000; Yates, 1999). To apply the MOL, one traverses the memory palace to encode the learning content deposited at the loci (Mann et al., 2017). Doing so, the learner uses his imagination to create realistic loci, links these with striking visual characteristics to the information, and then forms a coherent route based on these loci. In order to strengthen the details of the memory palace to preserve it as long as possible, the act of walking mentally through the palace has to be trained. Therefore, the learner needs to iterate the route several times. The intensity of the training phase varies between two hours and several iterations of a few hours per session Legge et al. (2012). The loci serve as hints when the learner tries to recall the information stored in the memory palace (Harman, 2001). That is done by mentally following the memorized route. As highlighted by Yates (1999), the art of memory (or mnemonics) has a traditional relationship to rhetoric. The MOL was taught to the orator as a strategy to "deliver long speeches from memory with unfailing accuracy" (ibid., p.2). Since the MOL happens exclusively in mind, some authors mention a few rules to facilitate the memorization and imagination process. For instance, the environment should be solitary and not crowded. About ten meters are the recommended distance between one locus and its successor. Every fifth loci, there should be a unique sign. Along the way, the environment should not repeat itself (Fassbender and Heiden, 2006). These rules are likely the authors' interpretation of the descriptions of Yates (1999, p.17):

"Consequently (in order that I may not be prolix and tedious on a subject that is well known and familiar) one must employ a large number of places which must be well lighted, clearly set out in order, at moderate intervals apart (locis est utendum multis, illustribus, explicatis, modicis intervallis); and images which are active, sharply denned, unusual, and which have the power of speedily".

As an easy example, suppose one intends to memorize a list of groceries. The list contains several items, too many to remember them easily. The first two items on the list are toilet paper and apples. The environment of choice, which has to serve as the memory palace, could be one's apartment. First, one enters the kitchen, and the first locus is the oven. One puts the toilet paper into the oven, turning up the heat and watches how it burns. That would be an example of an item - locus combination with striking imagery. Plus, the oven would be a locus which usually has nothing to do with toilet paper, so this scene would likely stick stronger to the mind than with an ordinary locus. Then, the apple could be placed in the microwave (the next locus). As a possible scene, one could imagine how the microwave is turned on, the light goes on, and the apple starts turning. Again, this would probably not happen in one's everyday life. Therefore, the imagery is strong enough to memorize the item "apple" along the route and in the memory palace.

In summary and derived from the literature, figure 2.4 illustrates the necessary steps for someone to learn and apply the traditional memory palace method.

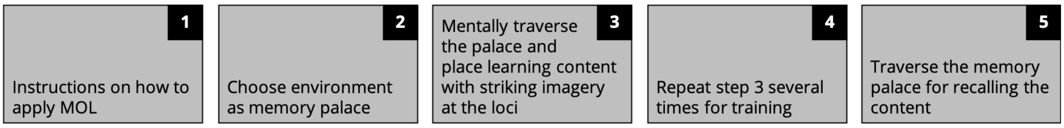


Figure 2.4: Steps to apply the MOL

However, research shows that mnemonics improve the memorization performance, memory capacity and the recall accuracy of the information learned (Bellezza, 1981; Bellezza and Reddy, 1978; Carney and Levin, 2001; Dresler et al., 2017; Legge et al., 2012; Maguire et al., 2003; Putnam, 2015). Researchers in the domain of neuroscience and psychology are still trying to figure out why exactly the MOL works so well. With the help of the brain imaging technology called "functional Magnetic Resonance Imaging" (fMRI)[2], neuroscientists investigated how the superiority of mnemonic strategies could be explained. For instance, Nyberg et al. (2003) found out, the application of the MOL resulted in increased brain activity of particular regions. Kondo et al. (2005) support this effect as they also found altered brain activity patterns after teaching and practicing the MOL with their subjects. Here, Kondo et al. (2005), Maguire et al. (2003), and Yin et al. (2015) agree, that the change of brain activity patterns indicate how the use of the MOL is related to the episodic memory (cf. section 2.1). The authors emphasize the central role of the *hippocampus*, a brain region associated with encoding episodic memories and navigational aspects (Bird and Burgess, 2008; Maguire et al., 2003). As described by O'Grady and Yildirim (2019), this could be a logical explanation for the MOLs superiority. The spatial context is an important aspect of the episodic memory since every moment of one's lifetime happens at a particular location. Hence, the MOL might exploit the hippocampus's encoding potential to

[2]FMRI is a technology to measure the brain's activity by finding differences in the blood flow in the different brain regions (Huettel et al., 2004)

link the learning content to spatial cues, strengthening the memorization process via the episodic memory.

2.3 Virtual Memory Palaces

Nevertheless, the traditional memory palace also has a few flaws. For instance, it is only stored in the users' minds. That means the knowledge and its structure and imagery is lost when the person's memory is lost. Additionally, the mental memory palace cannot be investigated or passed on if needed (Fassbender and Heiden, 2006). As already described in "The Art of Memory": "[...]mnemonics can use what were afterwards called 'fictitious places', in contrast to the 'real places' of the ordinary method" (Yates, 1999, p.8). Hence, researchers began to invest their time into a concept where the MOL is trained in a virtual environment. That allows the exploration of virtual rooms and buildings. The feeling of being an integral part of the environment reduces the burden of imagining too much imagery (Fassbender and Heiden, 2006; Hedman and Bäckström, 2000). It may also support the perception of scenery that will stick to the user's episodic memory, as explained before. Therefore, the use of a computer and the supposed, simplified

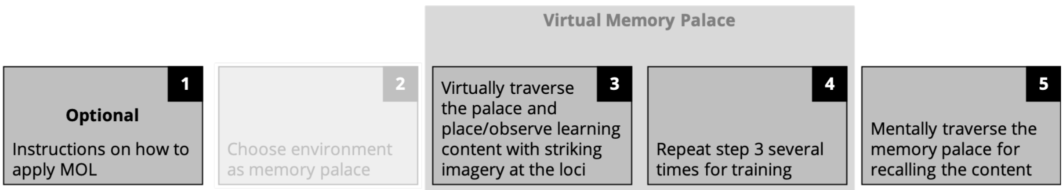


Figure 2.5: Steps to apply the virtual MOL

application of the MOL increases the users' memorization performance (Harman, 2001; Wong and Storkerson, 1997). These virtual environments, mostly three dimensional, can be explored by the help of an avatar (first-person perspective) which is navigated by the user (cf. (Fassbender and Heiden, 2006; Hedman and Bäckström, 2000; Legge et al., 2012)). The results of two studies indicate an at least equal effectiveness of the virtual MOL or VMPs compared to the traditional MOL (Fassbender and Heiden, 2006; Legge et al., 2012). Summarized, the current VMP concept suggests to use a virtual environment in the training phase of the

MOL (cf. figure 2.5). Note that, earlier research about VMPs did not always

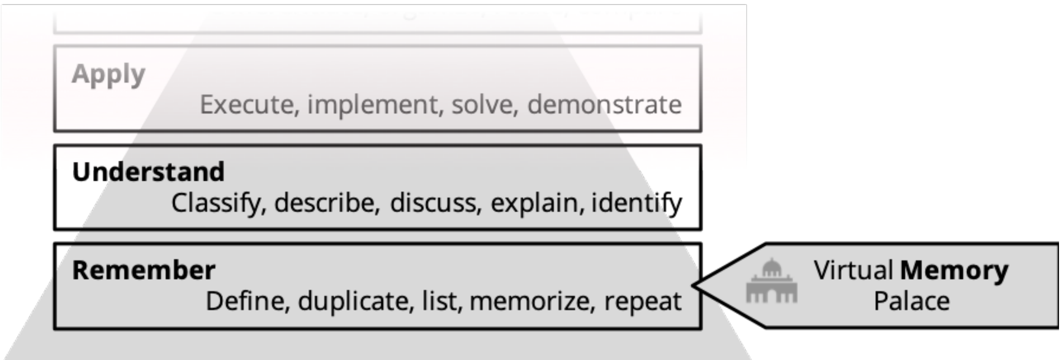


Figure 2.6: The VMP facilitates Memorization

include a step to explain to the users how the MOL works. However, this issue will be discussed and analyzed in the later chapters 3, 4, and 6.4. The second step does not apply when using a VMP since the environment is given by the designer of the VMP and does not originate from the user's mind. Steps three and four are performed in the VMP, while step five, the recall of the information is done in mind. The traditional MOL and the modern VMP concept address the first level of Bloom's taxonomy of learning, (cf. figure 2.6) since their main goal is to facilitate the learner's memorization performance (cf. section 2.2). However, a deeper analysis of earlier work about VMPs, in general, will be given in chapter 3.

2.4 Design

As already implied by the title of this thesis, the design of VMPs will be a central aspect of the succeeding chapters. Therefore, a description of what design is and how it is understood in science is given in the following. Simon (1996, p.2) highlights the relevance of design as being a crucial part in today's everyday life: "The world we live in today is much more a man-made, or artificial, world than it is a natural world. Almost every element in our environments shows evidence of human artifice." People are surrounded by outcomes of human design processes. That applies not only to concrete objects like buildings, vehicles for transportation, or the food we eat, but also to abstract laws, concepts, and processes people designed. For example, such entities are manifested in symbols and signs like emergency exits or traffic lights. However, there are many slightly different definitions of what design is. For instance, the *Oxford English Dictionary* defines it as "A plan or drawing produced to show the look and function or workings of a building, garment, or other object before it is built or made."[3] Wikipedia describes design as "[...] a plan or specification for the construction of an object or system or for the implementation of an activity or process, or the result of that plan or specification in the form of a prototype, product or process".[4] Vaishnavi et al. (2019) refer to design as bringing something into being or to invent something. That implies that designing aims to build an artifact that does not exist yet. Artifacts are artificial entities, built by men, and are supposed to serve a predefined purpose (Simon, 1996). However, all these definitions of design describe a plan that brings objects, processes or other, abstract entities into existence. Hence, these descriptions imply that design encompasses two important elements: the artifact as an outcome and the design process that starts from "nothing" or "something" and results in "something new".

The artifact of interest in this thesis is the VMP concept, which consists of elements like the virtual environment, its features, and functions, or how to use it. Hence, the upcoming chapter describes the conducted literature review, which will point out how the design of a VMP is worth investigating.

[3]Source: https://www.lexico.com/en/definition/design, accessed on 07.06.2020

[4]Source: https://en.wikipedia.org/w/index.php?title=Design&oldid=965604052, accessed on 07.06.2020

3 Literature Review

As mentioned earlier, the MOL is an ancient mnemonic strategy, and still one of the most powerful ones. Over the years, a research community represented by various scientific domains has already conducted a plethora of studies focusing on the MOL. The corpus of related literature is manifold and extensive, not only in the scientific domain. This chapter covers a structured, concept-centric literature review to illustrate the situation at the beginning (2016) and the end of this dissertation (2020) for the research area of VMPs. Besides others, the last chapter (8.2) also emphasizes present research gaps in order to recommend issues for future research. Therefore, the synthesis of the review will start results from 2016 in order to show the motivation of this research approach. These synthetic interim results will be labeled as such. After that, a complete overview is given to highlight the later research issues that were addressed over the years until now. The idea is to illustrate the overall research stream with its relevant characteristics. Especially the open research gaps shall be highlighted. The literature review was conducted in the English language only and according to the steps suggested by Webster and Watson in 2002 (Webster and Watson, 2002). Following their review process, this analysis started with searching for relevant articles which are published in scientific journals and conferences of higher quality (e.g., considering their reputation and H-index[1]). Compared to others, the articles of Legge et al. (2012), Börner (2001a) and Harman (2001) turned out to be the ones being

[1] The h-index measures the productivity and citation impact of scientific publications. The scientist's most cited papers and the frequency of other publications citing these papers are the base of the h-index. It was developed in 2005 by Jorge E. Hirsch, that is why it is also called the Hirsch index. Source: https://en.wikipedia.org/w/index.php?title=H-index&oldid=949215341, accessed on 08.04.2020

published in the best journal and conference ("Acta Psychologica", H-index = 88 and the Proceedings of the "Conference on Human Factors in Computing Systems", H-index = 165). Note that as proposed by Webster and Watson, the search did not only focus on information system (IS) databases. Since the traditional MOL was intensively studied in other domains such as psychology and cognitive sciences, it is reasonable to include a database like PubMed [2] as well. Hence the following databases were used to search for relevant studies: Scopus, AIS Electronic Library, PubMed, IEEE Library, and ACM Digital Library. Considering the descriptions used in relevant publications that deal with the traditional MOL or memory palaces, these exact terms had to be in the upcoming search query (Maguire et al., 2003; McCabe, 2015; Putnam, 2015; Roediger, 1980; Yates, 1999). In order to find publications that virtualized or visualized the MOL, it is assumed that authors somehow mentioned or described this process in one way or another. An initial search using Google Scholar brought up several studies including Fassbender and Heiden (2006) or Legge et al. (2012). Fassbender and Heiden described their concept as "Virtual Memory Palace", whereas Legge et al. (ibid.) referred to the concept as a "virtual environment as the basis for the MOL" (Fassbender and Heiden, 2006; Legge et al., 2012). Further query terms were then selected based on the same principle: the first seed of literature was analyzed to determine a set of terms that describes the concept of the virtual memory palace. In addition to that, synonyms were also considered as part of the search query. During the search and review process, the query was iteratively improved if a study was found with a new description for the VMP concept. The final search query was composed of two semantically different parts. The first part was meant to express how any kind of technology supported the MOL. The second part should cover the idea of a mnemonic strategy. Both parts were connected by the logical "AND" operator to indicate that both had to occur in the resulting documents. Within each part, the

[2] PubMed is a search engine that crawls the MEDLINE database regarding biomedical studies and life science publications. PubMed is maintained by the United States National Library of Medicine (NLM) at the National Institutes of Health. Source: https://en.wikipedia.org/w/index.php?title=PubMed&oldid=946358399, accessed on 08.04.2020

terms were connected by the "OR" operator to ensure that at least one of them occurred in the document:

(Augmented OR Immersive OR Virtual OR "Virtual Reality" OR Digital OR "digitally supported" OR "computer supported" OR "3D application" OR "Computer based learning" OR "virtual environment" OR "spatial electronic" OR Interface) AND ("Loci Mnemonic" OR "Mind Palace" OR "Memory Palace" OR "Method of Loci" OR "memory mnemonic" OR Mnemonic OR "memory journey" OR "journey method" OR "art of memory" OR "spatial mnemonic")

The next subsection gives a short and descriptive overview of the updated results from April 2020 and, as mentioned above, a throwback to 2016. After that, the contents of the publications will be analyzed in order to derive the research question. A complete overview of the concept matrix, including all the studies and their characteristics, is attached as Appendix 8.2.

3.1 Descriptive Analysis

Summarized, 934 distinctive publications resulted from the databases mentioned above (Scopus: 321, AIS Electronic Library: 70, PubMed: 307, IEEE Library: 214, ACM Digital Library: 22). In order to identify those publications that were actually relevant to this research approach, the selection was performed in three iterations. The first iteration was meant to sort out those publications that were identified as irrelevant due to their title. In the remaining set of papers, the second iteration included the scanning of the abstracts. The third iteration focused on a full-text analysis. In the end, 30 publications were left and considered as relevant for this thesis (excluding the ones of the author, see chapter 6). The oldest relevant paper was published in 2000 and the youngest one in 2020.
Taking a look at the number of published papers over time indicates that the topic became more and more interesting to the research community (see figure 3.1). 2017 marks a point where the number of publications clearly increased with a

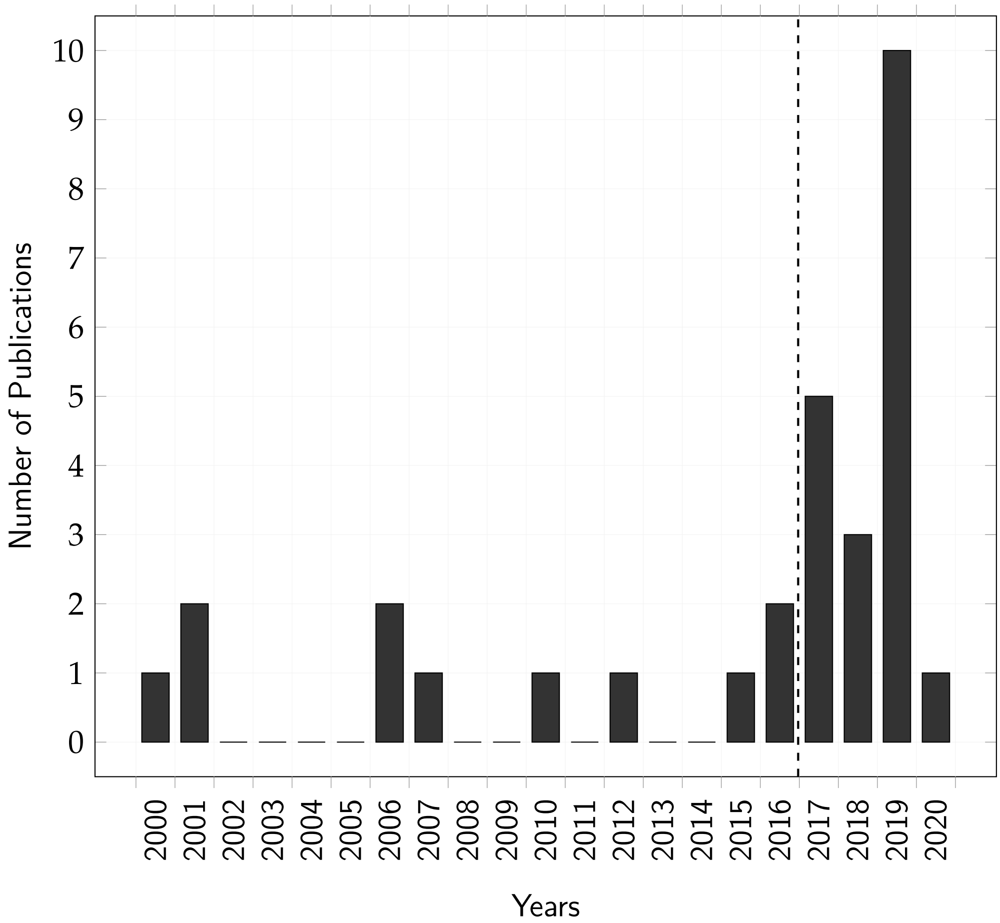


Figure 3.1: Distribution of Publications

maximum peak in 2019. Until 2017, basically at the beginning of this dissertation, the number of publications was quite sparse with only 11 studies over a 16 years span (see dotted line).

Another interesting aspect is the diversity of scientific domains from which the contributing authors stem. Resembling a power-law distribution, roughly 50% of the studies (considering the first author) were written from computer scientists and information system scientists. However, the other half, the long tail, stems from a variety ranging from architecture design to neuroscience and psychology (see figure 3.2).

That is probably due to the scientific origin of the traditional MOL. It was intensively studied in psychology and cognitive sciences (Legge et al., 2012), where it was found to be an interesting strategy to learn more about the human memory (Maguire et al., 2003). Combined with other technology-oriented domains, the

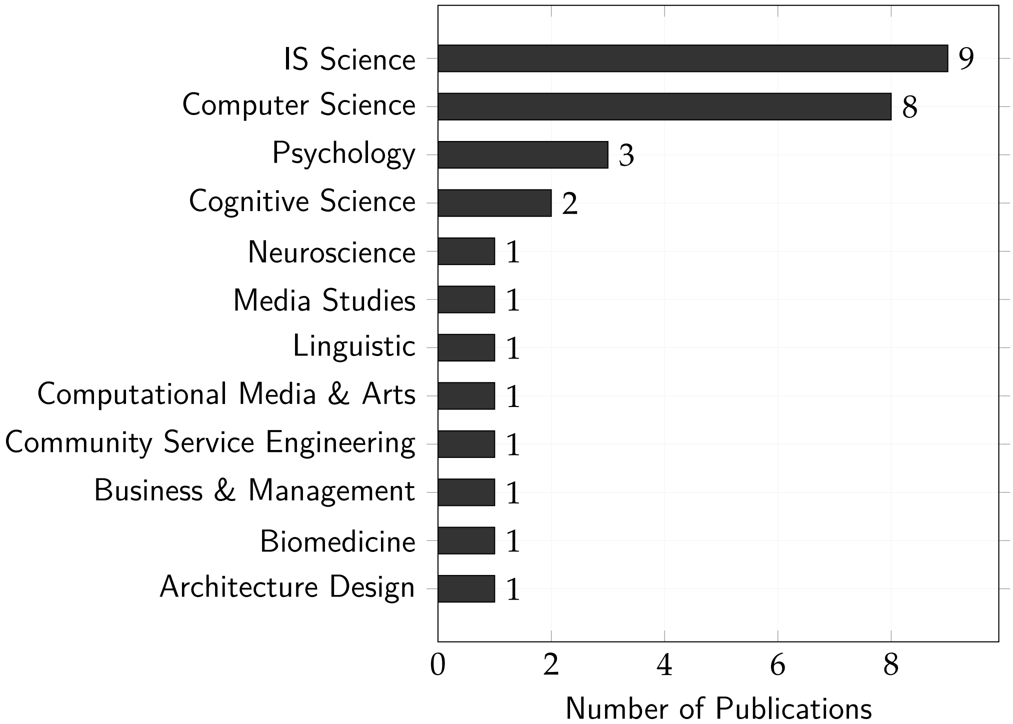


Figure 3.2: Distribution of Domains

overall distribution of different scientific areas gives the VMP research community a remarkable multi- and interdisciplinary character. In addition to that, a closer look at the authors reveals that the community is spread around the globe. However, at this point, the distribution is not remarkably different from other scientific topics or domains in general [1]. The papers stem from the United States of America, Europe, a few from China and two from Australia. Figure 3.3 shows a map with the corresponding cities from where the authors published the articles.

Further differences can be found in the type of publications. Approximately two-thirds of them were published in conference proceedings (22) while the rest were found in journals (8). Sixteen of the papers were found to be research-in-progress studies. Either the authors described them as such, or they were categorized as such due to some essential parts not performed yet, for instance, any evaluation of a prototypical VMP. The other 14 papers were identified as full papers in terms of a completed research phase. That would include the fundamental parts, such as

[1]Source: https://www.nsf.gov/statistics/2018/nsb20181/report/sections/academic-research-and-development/outputs-of-s-e-research-publications, accessed on 11.04.2020

Figure 3.3: Map of the Publications' Origins

the research motivation and -question, the methodology, any kind of prototypical development, an evaluation phase, and a discussion.

3.2 Content Analysis

In addition to the meta-information, this subsection will give an overview of the relevant issues of the papers' content. The analysis will start at a high-level, followed by a discussion of more detailed aspects to determine the research challenges. The first categorization that divides the initial set of papers, hence the ones that were available at the beginning of the dissertation (in sum 11, see fig. 3.1), is the type of the research approach. Nine of the studies chose an application-oriented perspective. That means the authors worked on a practical solution, like a certain technology built on scientific theories and models (Roll-Hansen, 2009). For instance, Hedman and Bäckström (2000) developed a VMP in order to see if users, in that case, students, could improve their memory and their ability to reflect better on philosophical learning content compared to those who did not use a specific method. Losh (2006) reported extensively about the use of a VMP for training soldiers for future missions in the Middle East. Foley (2010) talked about a VMP concept that is meant to serve postgraduate students to virtualize their ideas and connect them to conceptual structures in a virtual environment called V.E.N.I.C.E (Virtual Environment for the Navigation of Ideas and Concepts in Education). These authors emphasized their intention to give their idea or prototype an applied-oriented purpose. However, two of the studies rather implemented a VMP in order to investigate more basic questions like how a VMP performs compared to the traditional MOL and if the environment of a VMP influences the memorization performance of the user. Legge et al. (2012) conducted an experiment and compared three different groups with each other: a control group, a group that used the traditional MOL, and the last one used a VMP. The VMP group participants were given one of three different VMP environments (warehouse, apartment, or school). The authors reported that the type of environment had no significant influence on the participants' memorization accuracy. It is noteworthy at this point that the study of Legge et al. (ibid.) is the widest one found in terms of participants (N=142) and the extend of the statistical data analysis. Jund et al. (2016) also conducted an experiment. They wanted to see how the memorization performance would be influenced due to different user-perspectives (ego- vs. allocentric view). These studies were labeled as "Basic Research" because they wanted to explain a certain phenomena or improve an existing theory (Schauz, 2014). In summary, these papers put a stronger focus on how the concept works, rather than if it works.

Interim Result #1: The Type of Research

The early studies primarily focused on applied approaches to show the potential that lies in the concept of a VMP. Nevertheless, the most extensive study among the search results addressed explanatory research questions.

Further differences that emerged during the analysis are manifold and yet have something in common. They are, to some degree, related to the design of the respective VMPs. The first irregularity that stood out was that authors referred to different levels on the theoretical backgrounds of memory palaces or the MOL. As seen in section 2.2, in order to build a traditional memory palace, Yates (1999) suggests considering certain guidelines. These guidelines, any reference to them, or at least a mention that they exist were only found in three of the eleven papers (published before 2017). For instance, Hedman and Bäckström (2000) describe so-called "Key Principles" (e.g., place like environments or striking imagery) that need to be regarded in order to build a memory palace. As described earlier, Fassbender and Heiden (2006) explain similar rules like the need for a unique sign that appears every fifth locus or that the environment should not be too bright or too dark. Losh (2006) mentions this kind of ruleset only in one sentence. The loci should be well lit and in moderate intervals apart from each other. Other authors like Foley (2010) and Legge et al. (2012) or Morel et al. (2015) do not refer to any rules for the design of a memory palace at all. Furthermore, those rules that were described vary substantially in the level of detail. Compared to the other authors, Hedman and Bäckström (2000) give the most detailed description and a brief reason for why each of these principles should work. Still, just like Fassbender and Heiden (2006) and Losh (2006) they lack a reference to any literature that explains why that principle should aid, for example, to improve the memorization performance of the user or serve any other desirable outcome.

Interim Result #2: Guidelines for Traditional Memory Palaces

Authors seem not to be fully aware of the theory that covers some guidelines for traditional memory palaces or do not consider them relevant enough to be mentioned.

Another design-related difference is found in the variety of the implementations of the VMPs. That becomes clear when the different aspects of every prototype are compared to each other. As a result, two sharply different domains were identified.

Choice of Display Technology

The central idea of a VMP is to give the user a visual template for her or his memory palace. Therefore, a medium or technology is needed to do so. Within the studies of the result set, the distribution of technologies looks as follows (either implemented or suggested as a concept): *Television (TV) screen* - 1x, *Desktop PC* - 4x, *projector*, *Virtual Reality (VR)* - 1x, *Augmented Reality (AR)* - 3x, *Personal Digital Assistant (PDA)* - 1x. [1] Note that one could also use any kind of canvas to paint or sketch a VMP. Also, one could use pictures as a template for the memory palace. That has already been done, but as Legge et al. (2012) commented, these approaches lack many aspects of the original MOL. Therefore, these approaches will not be considered in this thesis.

Degree of Visualization

The degree of visualization refers to the question of which elements of a memory palace were implemented or conceptualized in the respective VMP. For instance, Fassbender and Heiden (2006) build a three-dimensional virtual castle where the loci were distributed in several rooms or hallways. The user could navigate through the castle in a first-person perspective. Hence, the person sat in front of a desktop PC and used a computer mouse and the keyboard to traverse the VMP. A similar but not equal implementation was found by Legge et al. (2012). The authors also build the memory palace as a three-dimensional environment that was explorable with a desktop PC, and the participant could navigate it using a keyboard and computer mouse. However, the loci were not implemented. Instead, the user had to imagine the objects being placed in the environment (see fig. 3.4, screenshot on

[1] **Virtual Reality** describes an environment sought to simulate an experience for the user. VR applications are, for example, found in the gaming or educational industry.
Augmented Reality is a digital augmentation of the real world. Computer-generated content is added via a display or other projecting technology to the real-world setting.
Personal Digital Assistants are small PCs, popular before the era of smartphones, built as a personal information manager.
Sources: https://en.wikipedia.org/w/index.php?title=Virtual_reality&oldid=967571481
https://en.wikipedia.org/w/index.php?title=Augmented_reality&oldid=966899768
https://en.wikipedia.org/w/index.php?title=Personal_digital_assistant&oldid=967635482, all accessed on 14.07.2020

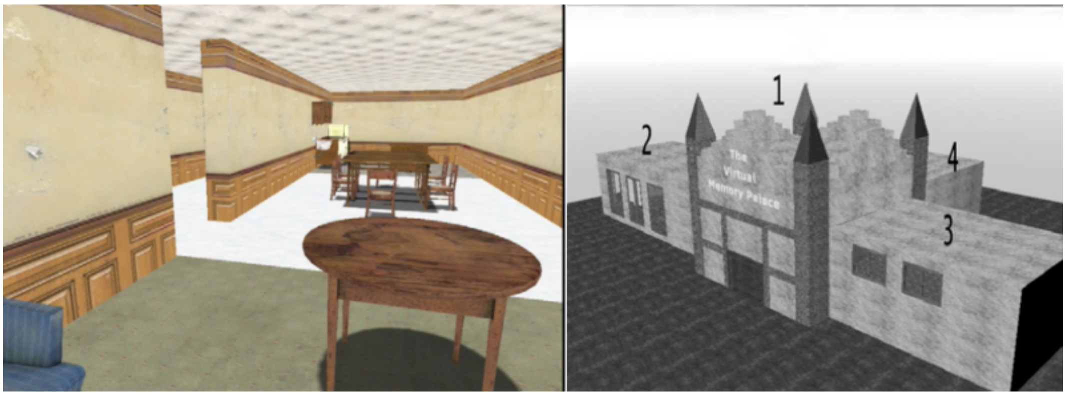


Figure 3.4: Inside and Aerial View of two VMPs

the left). In the studies where the prototypes contained the loci, the media richness of the loci varied as well. So even if they were part of the VMP, some consisted of images and a text or text only, some included three-dimensional objects and Fassbender and Heiden (2006) even equipped the loci with interactive features. Additionally, as seen above, some studies used AR technology as a medium to implement the VMP. This approach differs substantially from the other ones since the "palace" is already given by a real-world environment. Hence, the authors focused on adding only the missing elements like the loci to the VMP.

As mentioned earlier, Harman's concept of 2001 was to cover a blueprint with hyperlinks. Hence, the user only receives an abstract two-dimensional template of the VMP, which is only observable from a bird's-eye view (Harman, 2001). In the studies of Börner (2001a) and Losh (2006) the user traversed the VMPs in a third-person perspective so that the user could control a walking avatar through the virtual environment.

The last major distinction found between the studies concerns the "palaces" themselves, hence, the virtual environment. Apart from the AR implementations, which used the real world as the memory palace architecture (Ikei et al., 2007; Morel et al., 2015; Rosello et al., 2016), the remaining eight studies needed to build a memory palace in a creative process. The outcomes show certain similarities and differences: The majority of the VMPs represent non-fictional environments like a school, an apartment, or a castle (Fassbender and Heiden, 2006; Jund et al., 2016; Legge et al., 2012). Börner (2001a) and Hedman and Bäckström (2000) decided to use fictional palaces like a museum that floats in outer space.

Another mentionable difference is that some studies informed the participants on how to apply the MOL (Fassbender and Heiden, 2006; Jund et al., 2016; Legge et al., 2012), while others seem to skip this part since they did not report on such a step (Hedman and Bäckström, 2000; Ikei et al., 2007; Morel et al., 2015; Rosello et al., 2016). While this aspect is not necessarily an integral part of the software, it rather associates with the design of the concept itself. Since the traditional MOL works only in the user's mind, s/he has to be informed or needs to educate herself about the method. A VMP can also be used without actually knowing what the purpose of the tool is. Hence, from a conceptual point of view, it is not clear, yet worth examining, whether exploring a VMP leads to an enhanced memorization performance even though one is not focused on applying the MOL.

Interim Result #3: The Design of the VMPs

The designs of the VMPs vary substantially in terms of the technology, the user perspective, the loci, the palace itself, and the instructions of the MOL.

Further noticeable aspects involve the experimental evaluation procedures. In six of the studies the prototypes were evaluated in an experimental setting to investigate if the VMP improves the memorization performance of the participants (Fassbender and Heiden, 2006; Hedman and Bäckström, 2000; Ikei et al., 2007; Jund et al., 2016; Legge et al., 2012; Morel et al., 2015; Rosello et al., 2016). So, while the experimental procedure varied among the studies (e.g., the number of participants or the exact protocol), the dependent variable was quite often the memorization performance measured by the recall accuracy. The outcomes of the studies show mixed results. Fassbender and Heiden (2006) as well as Ikei et al. (2007), Legge et al. (2012), and Rosello et al. (2016) report on an improvement of the memorization performance compared to uninstructed, rote rehearsal strategies. Hedman and Bäckström (2000) could not find any evidence that their VMP facilitates the memorization process or recall ability. Jund et al. (2016) compared a VMP against a scenario in which the user is fixed in space. Hence, she or he could not navigate, and the to-be-remembered items appear, one after another, in the user's field of view. As a result, they concluded that this latter virtual world outperforms the VMP concept.

Except for two, all of the studies that involved an evaluation phase recruited students as participants. Losh (2006) reported on the virtual environment "Tactical Iraqi" which, as mentioned above, was designed for soldiers. Morel et al. (2015) built their VMP to aid patients who have dementia and also evaluated it with them.

Interim Result #4: The Research Methodology

An experimental, quantitative evaluation is the dominant procedure, but the parameters vary substantially: number of participants, number and order of experimental phases, extend of the empirical analysis, and the results.

Interim Conclusion

This interim conclusion of the literature review represents the initial set of relevant studies for this thesis and its research approach. Referring to the papers found until the year 2016, the following insights are derived from the content analysis: The majority of the research community shows a remarkable intent to implement a VMP concept for a diverse field of use cases. That implies the potential that is assumed and also promoted by the researchers. However, earlier approaches are more of an explorative nature; the first walk attempts, so to say. The fact that five of these eleven studies are research-in-progress papers emphasizes the early stage of the topic's maturity. Furthermore, the original idea of how to build a VMP differs strongly among the studies (technology, degree of visualization, user's awareness of the MOL). The experimental evaluation procedures are also quite diverse and therefore hamper a direct comparison between the studies.

Analysis of the Studies from 2017 until 2020

Since the first eleven papers are now described, the remaining 19 shall also be considered and reflected against the interim conclusion. Considering the first interim result, the type of research shows that application-oriented approaches are still dominant. However, the proportion of the research papers investigating explanatory research problems to describe certain phenomena has changed. Among the 19 newer studies, there are seven "basic research" studies identified. Consequently, the percentage doubled from 2 of 11 (approx. 18%) to 7 of 19 (approx. 36%). For instance, Reggente et al. (2020) analyzed whether an editing feature for the loci would improve the users' recall performance compared to predefined, unchangeable loci. Liu et al. (2019) followed a similar question and investigated the influence of interactive features on the users' recall performance. Krokos et al. (2019), O'Grady and Yildirim (2019), and Vindenes et al. (2018) focused on the influence of the choice of technology on possible effects but primarily, again, on the participants' recall ability. Peeters and Segundo-Ortin (2019) propagate the use of VR as the medium of choice for a VMP. Interestingly, their contribution did not include an experiment, but they derived their conclusion solely on reviewing the literature, and deductive reasoning. Additionally, the authors recommend further design-related features like certain lighting to emphasize the loci or sensorimotor realism, hence, the perception that the virtual environment appears as real as possible. Therefore, it is concluded that the research community's intention to demonstrate proof of concepts of a VMP is now accompanied by the motivation to explain how and why certain designs work better than others.

Regarding the second interim result, it is found that the diversity of the theory cited to argue for certain design guidelines also increased. For instance, Caluya et al. (2018) refer to the importance of grids, landmarks (Scarr et al., 2013), and the loci saliency in order to facilitate the memorization process. Caplan et al. (2019) consider the familiarity with the architecture of the palace as an interesting factor for the memorization process. However, the overall use of any kind of theory in order the reason for a specific design of a VMP is still highly diverse. Ten of the studies did not mention any theory at all (Csapó et al., 2018; Das et al., 2019;

Huynh et al., 2019; Leyer et al., 2019; Liu et al., 2019; Mann et al., 2017; O'Grady and Yildirim, 2019; Raso et al., 2019; Reggente et al., 2020; Yamada et al., 2017) and the other nine papers refer to different literature with strong varying extend (Caluya et al., 2018; Caplan et al., 2019; Gelsomini et al., 2020; Hagström and Winman, 2018; Irie et al., 2017; Krokos et al., 2019; Peeters and Segundo-Ortin, 2019; Ralby et al., 2017; Vindenes et al., 2018).

The third interim result is also still valid. The variety of the VMP implementations again shows different types of technologies, different assumptions underlying the design of the palaces, and different approaches to illustrate the loci and the learning content. However, it is worth mentioning that the distribution of technological choices changed: *CAVE* [2] - 1x, *Desktop PC* - 6x, *VR* - 8x, *AR* - 6x, *Smartphone* - 1x. Hence, the studies favored the use of augmented and virtual reality technologies, like head-mounted displays (HMD) or even the CAVE, over handheld and desktop screen solutions. That might be due to general advances achieved in AR and VR technologies during this period (Guazzaroni and Pillai, 2019) or due to the positive influence of immersive virtual environments on the memorization performance (as to be seen in the later sections 6.1 and 6.3).

Another conspicuousness was identified concerning the discussions and results of the studies. Compared to the first eleven papers, the later ones did not only refer much more often to design-related aspects (as described above), but also concluded with design recommendations for future research (Caplan et al., 2019; Liu et al., 2019; O'Grady and Yildirim, 2019; Peeters and Segundo-Ortin, 2019; Ralby et al., 2017; Raso et al., 2019; Reggente et al., 2020; Vindenes et al., 2018).

The last interim result also applies to the later studies, but it is worth mentioning that the average number of participants of the evaluations increased (until 2016: avg=30.1 ,med=14; 2017-2020 avg=45.4, med=31). Combined with the fact that the number of publications also increased over the years (see subsection 3.1), this may indicate a rising research interest in the topic.

[2] A Cave Automatic Virtual Environment (recursive acronym CAVE) is a technology that offers an immersive virtual reality environment. The idea is to have a room where projectors are directed to each wall. This way, any virtual surrounding can be simulated for the user. Source: https://en.wikipedia.org/w/index.php?title=Cave_automatic_virtual_environment&oldid=951756914, accessed on 19.04.2020

The following section aims to synthesize the observations that regarded the studies until 2016 to identify a valid research gap.

4 Research Question

The previous analysis revealed promising approaches to VMP concepts. However, it was shown how diverse the previous research contributions are. The differences of the approaches range from the used technologies, the design of the environments and loci, the users awareness of the MOL, to the theoretical foundation of the VMP concept, the experimental procedures, or the exact methods to measure the memorization performance. Despite these different designs, there is still a lack of a comparison between them or specific design parameters. Hence, some central questions arise: Due to the mixed results and unequal evaluation methods of the experiments, are there good and bad ways to design a VMP? What means "good" and "bad" in this case and what makes a VMP a good one? As described in sections 2.2 and 2.3, the idea of a traditional memory palace and also of a VMP, is to improve the users memorization performance. That is why the majority of the researchers set up experiments to measure whether the participants could improve their recall accuracy by the help of a VMP. Therefore, a "good" design may involve many aspects but the one factor that is crucial for a VMP and its design is that it improves the users' memorization performance. A question that is not only a legitimate derivation from the literature review, but also aims to produces practical implications, is formulated as follows: **Does the design of a VMP influence the memorization performance of the user?**

As illustrated in the last section, the parameters that differentiate the earlier VMPs in their designs are predominantly found in the choice of technology, the degree of visualization, and as a non-technological feature, but in the conceptual context: the instruction on how to apply the MOL, hence, the users awareness of the MOL. These three domains are therefore selected to address the relevance of the VMP design and its influence on the users' memorization performance.

Choice of Display Technology

As seen in the interim results of the last section, authors used different technologies for their VMP prototypes. Up to the beginning of this research project, the prevalent technologies were: desktop PCs, a projector, VR, AR, a PDA, and a TV screen. One could certainly create a study design in which all available and reasonable technologies would be compared. However, the downside of such a study design is that the results would not necessarily be transferable to future technologies or more advanced versions of those available. Hence, rather than listing, analyzing and evaluating the plethora of technological differences among these displays, this subsection suggests a property of display technologies that may guide developers of VMPs in the selection process. It is necessary to abstract from the specific type of technology to the purpose and role it plays in the application of a VMP. As seen in section 2.3, the concept of the VMP is to give the user a visual template that later serves as a mental projection, hence, the memory palace. One property of display technologies is the degree to which they support of facilitate the users' immersion into the virtual world or scene. Immersion or immersive presence describe the perception of being in a particular place even one is physically in another (Witmer and Singer, 1998). This property varies among different display technologies, e.g. a desktop screen and a HMD (Ragan et al., 2010). Interestingly, the immersive experience in a virtual environment (VE) also supports certain mental processes and factors that may arguably be essential for the process of implementing a VE in the users mind as a memory palace (Huttner and Robra-Bissantz, 2016, p.3):

"Proven to be crucial for a successful performance in virtual environments (VE), immersive presence may reduce the cognitive burden, which is associated with task performance (Agarwal and Karahanna, 2000). It is therefore positively correlated with task performance (Witmer and Singer, 1998) and significantly impacts per-

ceived enjoyment and performance (Liu et al., 2014). Furthermore, it is found to have a positive influence on learning and engagement as well (Bredl et al., 2012; Dede, 2009) and it may even foster the user's memory recall performance regarding virtual objects, the spatial layout or even procedural knowledge (Lin et al., 2002; Mania and Chalmers, 2001; Ragan et al., 2010; Sowndararajan et al., 2008)."

It is therefore concluded, that a comparison of two different display technologies with a different immersive property plus an assessment of the users' perceived level of immersion may indicate the technological fit of a display for the concept of a VMP (see section 6.1 & 6.3).

Degree of Visualization

Referring to the so called *generation effect*, where words that are generated in the human's mind are better memorized than those that are predefined (Slamecka and Graf, 1978), Huttner et al. (2018, p.276) described the problem as follows: *"Clearly, the loci design of past studies varies substantially. This might be due to the fact that, besides others, the traditional MOL is performed completely in mind. Earlier studies that transferred the MOL into a virtual world context did not explicitly evaluate to which degree the method should be performed in mind, especially regarding the conceptualization and design of the loci. Since the traditional MOL heavily relies on the idea to mentally establish an individual, unusual and unique visual association between an item and a locus, it seems questionable whether a predefined and integrated locus is better suited for the memorization process than a completely mind-based locus. Therefore, this study aims to answer the research question whether in a VMP, the concept of imaginary or visualized locus leads to better user memory."* Hence, the study #3 in section 6.2 describes the investigation of the loci design with different degrees of visualization.

Users' Awareness of the MOL

In sum, seven of the studies until 2016 conducted studies that involved an evaluation phase in which the participants could have been educated about how the MOL works. Only three of these papers mention that this had been done. As briefly explained in the theoretical backgrounds (section 2.3) and also derived in the literature review, the conceptual design of a VMP may or may not include an explanation of the MOL. Hence, the assessment of this design aspect regarding its influence on the memorization performance does not only address the research question of this thesis, but has also practical implications as mentioned in the authors publication from 2019 (see section 6.4) (Huttner et al., 2019a, p.2): Following the traditional MOL protocol *"[...] users still have to be trained or informed of the mnemonic before they enter the VMP and apply this method; that is why a further improvement of MOL would be necessary to minimize the mental effort of users. Previous lab studies were mostly conducted under the condition that participants were already informed about the MOL (Brehmer et al., 2007; Dresler et al., 2017; Huttner et al., 2018; Huttner and Robra-Bissantz, 2017; Jund et al., 2016; Legge et al., 2012; McCabe, 2015; Ng et al., 2010; Roediger, 1980). [...] it offers great opportunities for e-learning application designers to apply this method without concerning about users' foreknowledge."*

The next chapter seeks to reflect on a legitimate research methodology and thus, explain the research model to frame the investigation of the three identified domains of interest.

5 Research Methodology

5.1 Epistemological Introduction

As one of the outcomes of the literature review shows, the VMPs differ substantially in their design aspects. In order to clarify this issue, a research question was derived. The upcoming discussion is epistemological and focuses on how to acquire knowledge. More specifically, it focuses on identifying a valid research paradigm and methods that legitimately address the research question and the identified design domains. The research intention of this thesis stems from the domain of information systems. The IS discipline formed in the 1960s and is therefore quite young compared to other domains like medicine, physics, or chemistry (Hirschheim, 2019). Due to its young age and some other factors that will be outlined in the following, the discussion about how IS researchers can or should conduct their research is ongoing (Gregor, 2006; Gregor and Henver, 2013; Kanellis and Papadopoulos, 2009; Vaishnavi and Kuechler, 2015; Wilde and Hess, 2007). Rudy Hirschheim (1985) illustrated the epistemological history of the IS discipline. His work will be referenced to, just like Becker and Niehaves (2007) and Kanellis and Papadopoulos (2009), since these authors also put the general problem of an epistemological position into the IS perspective.

Hirschheim (1985) points out, how the epistemological position of a research approach needs to answer a question every researcher has to address: How do we acquire knowledge without being able to do it from an absolute viewpoint? As a researcher, we are always influenced by many factors like our language or culture. Therefore, knowledge should be defined differently from objective truth. It would rather be reasonable to assert the correctness of knowledge claims with the help of empirical methods. That leads to an interpretation of knowledge in a probabilistic sense. "Knowledge is therefore not infallible but conditional; it is a societal convention relative to both time and place. Knowledge is a matter of societal (or group) acceptance." (Hirschheim, 1985, p.1) Second, a valid strategy is needed, which allows the researcher to generate more knowledge. However, what is valid in this context? Science or the "scientific method" in the West is a convention that is heavily influenced by its cultural and societal norms. Thus, a scientific method has to address these norms in order to be seen as valid. Nevertheless, the challenge at this point is not only to identify adequate methods, like a craftsman who needs to find the right tool for a specific task. Hirschheim points out: "for he who has but one tool, the hammer, the whole world looks like a nail"(ibid., p.2). It is more like the researcher can be seen as a tool builder who creates a unique tool for a specific problem. Note that this is represented by the research model in the later section 5.3.2.

5.2 Relevant Research Paradigms

Other researchers also investigated the role of the different paradigms in the scientific domain of information systems (Benbasat and Weber, 1996; Klein and Myers, 1999; Wade and Hulland, 2004), and there are plenty of them that emerged over time. They influenced each other, coexisted, preceded, or followed one another (e.g., pragmatism, constructivism, idealism, empiricism, subjectivism, or realism) (Hirschheim, 1985). For the upcoming discussion, the focus shall be laid on the relevant streams of prevalent paradigms. Concerning the results of the literature review and the derived, design-oriented research questions, these paradigms are the major streams: positivism, anti-positivism (ibid.), as well as post-positivism (which is more like a paradigmatic movement than a real paradigm in the Kuhnean sense), and the design science research paradigm (which implements a post-positivistic perspective as to be seen later) will be described. (Hassan and Mingers, 2018; Hirschheim, 1985; Kanellis and Papadopoulos, 2009; Niehaves and Bernd, 2006)

Hence, this subsection will briefly describe these schools of thought in order to explain the epistemological context of this thesis.

Positivism

Positivism represents a major paradigmatic stream in multiple disciplines and slowly emerged in the late 12th century. Without diving in too deep the historical origin of positivism, it is yet notable that Auguste Comte, Isaac Newton, David Hume, John Locke, and Galileo Galilei can be seen as some of the most influencing personalities that formed the positivistic thought (Hirschheim, 1985; Kanellis and Papadopoulos, 2009). According to Burrell and Morgan (2011, p.5) positivism "seeks to explain and predict what happens in the social world by searching for regularities and causal relationships between its constituent elements". In order to do this, there are particular ontological positions and methodological principles to follow. Hirschheim (1985) describes five of them as central pillars of positivism:

1. **The unity of the scientific method:** The scientific method represents the only valid approach to acquire new forms of knowledge and strictly follows conventions like replicability and empiricism. The idea is that knowledge is acquired by developing a hypothesis and then trying to disprove or support it. Unity in this context refers to the overall validity of the scientific method. It is seen independent from the domain of study: "human, animal or plant life; physical or non-physical phenomena; etc." (Hirschheim, 2019, p.3)

2. **Humean causal relationships:** David Hume outlined three fundamental prerequisites for a relationship to be seen as a causality between A and B, assuming that A causes B. First, there exists a general association between both entities. Second, A needs to occur before B, and third, there has to be a spatial and temporal connection between them (Hume, 2012). This aspect of positivism shows the underlying desire to seek regularity and structure in the elements of study. Therefore, the domain and entities of study are analyzed and reduced towards their constituent parts.

3. **Empiricism:** The gathering of data, which is seen valid as the (common) senses experience it. Everything that is a different form of information, such as an extrasensory experience or a subjective perception, is not tolerated.

4. **The absence of an intrinsic value position in science:** The science process has to be free of subjective values, political, ideological, or moral beliefs.

5. **Logic and mathematics build the scientific foundation:** As universal languages, these two quantitative approaches are important tools to reveal causal relationships.

The positivist approach embraces an ontological position of realism. Hence, that is a viewpoint from that the universe and its entities exist and function on their own, independently from any observer. This perspective correlates with the fourth pillar, the researcher who only observes and analyses, without being driven by intrinsic values. Such aspects of positivism might lead to possible limitations because they prescribe the same methodological principles for natural and social sciences.

Anti-positivism

As the name already implies, anti-positivism (or interpretivism) tends to reject the central aspects of positivism. Rather than focusing on research methods that draw their validity from experience or humean causality, the anti-positivistic position favors dialectic based approaches and seeks to overcome the static view of the positivistic school. Early anti-positivists saw a lack of deep understanding of the studied phenomena in the social sciences. The goal was to make sense of the researchers' observations, which are believed to be socially constructed, a product of the human mind (Hirschheim and Klein, 1989). For instance, a position of ontological idealism (a form of anti-positivism) is assumed, when "researchers believe that abstract or mental entities have some sort of reality 'independent' of a 'real world', that is, if they perceive reality as a construct dependent on human consciousness" (Becker and Niehaves, 2007, p.203). In the anti-positivistic form called constructivism, the view ranges from the idea that the construct "objective reality" is only an interpretation of the individual (Burrell and Morgan, 2011; Klein and Myers, 1999; Walsham, 1995) up to the assumption that there is no such thing as an "objective reality" (Von Glasersfeld, 1986). Hence, as social beings, we should be analyzed in the context of our social and cultural existence. Klein and Myers (1999) shall be referenced here to give an impression of an anti-positivistic research endeavor. The authors proposed seven principles for a field research approach:

1. **The Fundamental Principle of the Hermeneutic Circle:** It is suggested that a crucial and fundamental part of understanding is to iteratively consider the parts of the whole and the whole itself.

2. **The principle of Contextualization:** The research analysis needs to critically reflect on the historical and social aspects of the issue of interest. Hence, the audience of the research is informed of how the studied situation evolved.

3. **The Principle of Interaction between the Researchers and the Subjects:** The researcher always has to be aware of her or his influence on the construction of data, since the interaction with the participants might cause significant effects.

4. **The Principle of Abstraction and Generalization:** While interpreting the gathered data, the researcher has to identify the idiographic details (see principles one and two) to relate these to general theories that describe the human nature and social action.

5. **The Principle of Dialogical Reasoning:** This principle emphasizes how the researcher has to be highly sensitive towards the fit between the gathered data and the assumptions and preconceptions that underlie the research design. Again, an iterative research process is suggested.

6. **The Principle of Multiple Interpretations:** The researcher needs to be aware of how participants may interpret the same situation differently.

7. **The Principle of Suspicion:** It is required to be suspicious and look out for possible "biases" in the participants' narratives.

These principles demonstrate the central ontological assumptions of the anti-positivistic school, focusing on people, social life, and the human mind and perception. The aim is to deeply understand the phenomena in their cultural and societal context to create insights and holistic knowledge. Some qualitative methods are typical in this paradigm: textual analysis, ethnography, participant observation, and case studies (Walsham, 2006).

Post-positivism

The post-positivistic view emerged in the second half of the last century (Hirschheim, 1985). Just as in the anti-positivism, post-positivists reject the static worldview of the researcher who is an objective observer only. However, rather than ignoring the whole paradigm, this perspective favors a combination of positivism and anti-positivism. Acknowledging the relevance and rationale of both, post-positivists argue that all the parts of conducting research (e.g., hypotheses, background knowledge, theories, methods, and the subjectivity of the researcher) are crucial but may influence the results (Robson, 2002). Hence, they strive for objectivity but are aware of the possible biases (Lindlof and Taylor, 2017; Miller, 2001; Robson, 2002). As a result of the combination of both paradigms and depending on the research problem, post-positivists follow a methodological pluralism: quantitative and qualitative methods (Lindlof and Taylor, 2017). Hirschheim already propagated this methodological pluralism for the IS domain back in 1985 (Hirschheim, 1985). He refers to Kuhn, who pointed out that a single methodological view ignores the anomalous nature of the human experience (Kuhn, 1970). Guba and Lincoln (1994) contribute three characterizing properties of post-positivism:

1. An objective reality exists, but it is not entirely knowable.
2. The researcher's perspective is subjective and, therefore, can only create insights with a certain probability.

3. Quantitative and qualitative methods are valid tools to support or reject hypotheses.

Such post-positivistic properties characterize Kantianism. Kant propagates to differ between 'things in themselves' (which he calls noumena) and those things that are perceivable to an observer (called phenomena) (Kant, 1996). He proclaims that both entities exist: Those that are independent (noumena) and those that depend on human consciousness (phenomena).

The Multi-Paradigmatic Perspective of IS Science

Two characteristics shall be outlined, that support a post-positivistic, multi-paradigmatic stance in the IS science. First, an information system is an artificial object. It is a combination of hard- and software designed by humans. Second, the application system operates in a societal context to solve a problem for the users (Laudon et al., 2016, p.14). As seen in chapter 2.4, these properties are exactly the ones needed to classify an IS as a design problem: first, it is an artificially created entity, and second, it is built to achieve a specific goal. Vaishnavi and Kuechler (2015) state that if the knowledge necessary to build an artifact already exists, then it is a routine design. Otherwise, the design is innovative. If it is innovative, the question arises on how to address the knowledge gaps scientifically, which are opened up by the innovative design (Vaishnavi et al., 2019). Simon (1996) explains how there is a structural difference between the investigation of natural and artificial phenomena. Hence, there is a need for another paradigmatic perspective, one that allows multiple views: the so-called design science or the science of the artificial. March and Smith (1995, p.253) described it as follows: "Natural science tries to understand reality, design science attempts to create things that serve human purposes. It is technology-oriented. Its products are assessed against criteria of value or utility - does it work? Is it an improvement?". Therefore, the research challenges in design science are distinctive from the natural sciences ones. The goal of design science is, amongst others, to contribute to the design knowledge base (Vaishnavi et al., 2019). This does, in turn, serve implementers of an artifact as an aid for the creational process. So, Markus and Robey (1988) outlined that in the IS science, using positivistic approaches only, would have to premise that the phenomena of interest are always free of values, one-dimensionally causal, and determinate. However, humans are social beings and a central part of the IS research issue. We tend to form a dynamic, subjective perception of reality in a cultural and societal context. For instance, a cause-effect relationship that was identified using a positivistic approach only might change in a comparatively short period (Kanellis and Papadopoulos, 2009). Moreover, the domains where information systems emerged are not only manifold but also fast-changing due to new technology and its influence on the domain-specific cultural development like in economics and finance or education (Borawska-Kalbarczyk et al., 2019; Coccoli et al., 2014; Day and Schoemaker, 2016). Therefore, over time a pure positivistic or anti-positivistic worldview might lead to a limited understanding of IS. Considering the first property of post-positivism, the objective reality is not only not entirely knowable. It is also altered, manipulated, or even designed by new and innovative information systems. For instance, consider how nowadays people communicate, consume, present themselves, or collaborate in their field of work. The economic and cultural change that was enabled by the use of certain IS is substantial. Of course, this does not only imply positive changes. For instance, in 2018, it was revealed that a company called *Cambridge Analytica* collected millions of Facebook users' data. The users did not know about it. The data was used to build psychological profiles which were then sold and used in the political campaigns of the republicans Rafael E. Cruz and Donald J. Trump, especially in social media (Chan, 2019; Confessore, 2018; Meredith, 2018; Smith, 2020). The actual influence of this strategy on the outcome of the US presidential election in 2016 is questionable. However, it certainly demonstrates the potential of how information systems may be used to change peoples' everyday life for the good or the bad (Rathi, 2019).

The second and third post-positivistic properties also hold in the IS research domain. Knowledge is generated and improved iteratively, for instance, in design-oriented research cycles (Peffers et al., 2007; Vaishnavi and Kuechler, 2015), and preferably with a certain degree of probability than proving causality between A and B to be one hundred percent true (Gregor, 2006; Hirschheim, 1985).

5.3 Epistemological Profile

The research question involves two central subjects: the design of a VMP and the user's memorization performance. While the user's memorization performance is a latent construct and the dependent variable for this research, the design of a VMP is operationalized by three representative domains: The technology used to implement the VMP, the degree of visualization of its crucial elements and the user's awareness of how the MOL works. Based on this premise, this section will describe the epistemological character of this approach. Referring to the second part of the research question (memorization performance), it will be shown that knowledge is mainly generated by a positivistic approach. However, the first subject of the research question involves the design of a VMP. It is essential to highlight the implications that come along with design-related problems. As explained earlier, the aim is not only to explain something but rather to innovate and create something new: an innovative learning environment. So there is not only a need to explain the researcher's ontological perspective and to contribute knowledge but also to encourage the community to further invest in the VMP design research. Beyond the discussion of epistemology, the upcoming section will, therefore, introduce a research methodology that arguably covers these issues.

Becker and Niehaves (2007) developed a framework in order to give the IS researcher a tool to find an epistemological profile. It consists of five central questions which shall be addressed in the following (see table 5.1):

1. **What is the object of cognition? (Ontological aspect)** This research is about investigating the influence of the design of a VMP on the users' memorization performance. Hence, there are two central objects of cognition: A software artifact and a mental process of the human being. Software is an entity designed by humans to fulfill a predefined task and, hence, part of the real world. This real-world is yet to be enriched by the IS being de-

Question	Position		
1. What is the object of cognition? (Ontological aspect)	**Ontological realism.** A world exists independently of human cognition, for instance, independent of thought and speech processes.	**Ontological idealism.** The 'world' is a construct depending on human consciousness.	**Kantianism.** There exist entities that are independent from (noumena) as well as dependent on human mind (phenomena).
2. What is the relationship between cognition and the object of cognition?	**Epistemological realism.** Objective cognition of an independent reality is possible.	**Constructivism.** The relationship of cognition and the object of cognition is determined by the subject.	
3. What is true cognition? (Concept of truth)	**Correspondence theory of truth.** True statements are those which correspond with 'real world facts'.	**Consensus theory of truth.** A statement is true (for a group), if it is acceptable to the group.	**Semantic theory of truth.** A condition for truth is the differentiation of an object and a meta-language.
4. Where does cognition originate?	**Empiricism.** Cognition originates from the sense. Such experience-based knowledge is called a posteriori or empirical knowledge.	**Rationalism.** Cognition originates from the intellect. Such non-experience-based knowledge is referred to as a priori knowledge.	**Kantianism.** Both experience and intellect are sources of cognition. Thoughts are meaningless without content, cognitions are blind without being linked to terms.
5. By what means can cognition be achieved? (Methodological aspect)	**Inductivism.** Induction is understood as the extension from individual cases to universal phases, the generalization.	**Deductivism.** Deduction is the derivation of the individual from the universal.	**Hermeneutic.** The understanding of a certain phenomenon is influenced by the pre-understanding of the entire/context.

Table 5.1: Epistemological Framework (Becker and Niehaves, 2007).

veloped, the VMP. As explained in the theoretical background (section 2.1), memorization and learning are neurological mechanisms that heavily depend on subconscious processes, which are, of course, interconnected to the human mind, but do exist in other mammals as well (Allen and Fortin, 2013). Therefore, the memorization process is identified as part of the human mind, but not as an abstract, real-world independent entity. Therefore, it is concluded that a tendency to an ontological realism is the fitting view for this approach.

2. **What is the relationship between cognition and the object of cognition?** As in the literature review described, the users' memorization performance is the object of cognition. By measuring the recall accuracy (e.g., by the percentage of a user's recall performance of a list of words, see (Legge et al., 2012)), it is possible to evaluate it independently from the subject, hence, the researcher. One could argue that applying this measure in a laboratory experiment involves a certain degree of constructivism. Since the researcher constructs the laboratory situation and the experimental design, they may contain a subjective part. Nevertheless, the focus of a laboratory experiment is to establish a controlled environment that enables the researcher to observe a certain causal relationship objectively (Wilde and Hess, 2007). Hence, an epistemological realism underlies this relationship between the researcher's cognition and the object of cognition. Combined with the first question, this thesis's research approach obtains a positivistic tendency (Chen and Hirschheim, 2004; Hirschheim and Klein, 1989).

3. **What is true cognition? (Concept of truth)** As just explained, whether the design of a VMP will influence the user's memorization performance is the question that will hopefully lead to an extension of truth. In order to do this, there are, in theory, several methods available (Baddeley, 1988; Sharps and Gollin, 1986). Some approached the problem of measuring the memorization using fMRI (Maguire et al., 2003) others applied more indirect measures like Legge et al. (2012). As explained above, the percentage of a user's

recall from a list of words was taken as an indicator of her/his memorization performance. As the outcome of this measurement does not depend on the researcher, it obtains an assumed status as objective (cf. Kirkham, 1992; Schmitt, 1994; Baumann, 2002). Hence, the hypotheses that belong to the research question state assumptions that depend on an objective, "real-world" entity: the users' memorization performance. Therefore, the concept of truth in this research approach is mainly given by the correspondence theory. However, as a side-note, it is considered worth mentioning that today's process of contributing scientific knowledge also depends heavily on the consensus of the reviewers in the peer-reviewed publication process. Therefore, to some degree, the generation of new scientific knowledge is based on a consensus theory of truth since other researchers judge the quality of the contributing colleague. So if the group of peers agrees on the work, the knowledge will be published and certified as being at least partially true.

4. **Where does cognition originate?** This question refers to whether a pure positivistic or pure interpretivistic view is legit to address the goals of particular research. At this point, neither one of these shall be the dominating perspective. While the research question of this dissertation is primarily addressed by positivistic methods, the overall perspective originates in the domain of IS science, which is, as described in the last section, a multi-paradigmatic discipline. The aim is to improve the applicability of the concept of VMPs. To enable implementers to develop VMPs for all kinds of educational settings, it could be necessary to address different issues than just the quantitative measured memorization performance of the user. Hence, interpretivistic approaches, like case studies or interviews, may be useful for other VMP related questions. In their paper about the epistemological issues in IS, Kanellis and Papadopoulos (2009) referred to Kant by saying that experience (positivistic perspective) and intellect/rationality (anti-positivistic perspective) are inseparable from each other when it comes to generating reliable knowledge (Kant, 1996). A perspective of Kantianism is also adapted in this dissertation.

5. **By what means can cognition be achieved? (Methodological aspect)** Referring to questions two and three, the choice of research methods will be abductive, deductive, and inductive. While abduction is not explicitly mentioned in the framework of Niehaves (2007), it is yet an obligatory part of the scientific process. Following the majority of previous VMP studies (see section 3), laboratory experiments appear to be widely considered as a legit method to address VMP related issues. Due to the fact, as shown in the previous studies, that the memorization performance can be quantified quite well as the recall accuracy, an experimental setting, and quantitative analysis is the favored method of choice. Nevertheless, before that, there is a phase in which a hypothesis needs to be built. In this dissertation, the analysis of the research question leads to three design-related domains of interest. The investigation of these three domains leads to the articulation of hypotheses as to be seen later in the contributions. This process of building the hypotheses, derived from existing kernel theories about mnemonics or cognitive sciences (other disciplines) is the abductive act (Fischer and Gregor, 2011; Vaishnavi and Kuechler, 2015). After that, a prototypical VMP needs to be implemented. That represents the deductive phase since the prototype is created based on the theoretical assumptions and kernel theories, here the MOL and its assumed neural mechanism, as explained in section 2.2. Finally, the experiment is conducted. The idea is to investigate one or more hypotheses by gathering empirical data from a sample of participants (Friedman et al., 1994). The data is analyzed, interpreted, and the results are taken as a quantitative foundation to reject or support the hypothesis or hypotheses. Therefore, the conclusion is derived inductively from individual cases to support a general assumption.

Summarized, the epistemological position of this research approach is characterized by positivistic methods but applied in a post-positivistic context of Kantianism, where also interpretivist approaches will help to improve the concept of a VMP. The following discussion suggests a suitable research methodology: A design-oriented framework of models, theories, and methods that enable the researcher to contribute knowledge to the community and the public.

5.3.1 Design Science Research Methodology

As mentioned at the beginning of the last section, the VMP design is a central part of the research question. This design is represented by three aspects of the VMP concept. However, there are also other design-related domains, as seen in the literature review. Besides that, there may be a need for further investigation of the VMP concept, not only to optimize the user's memorization performance but also to address other factors. For instance, this could be fundamental IS issues like how much fun a VMP is to use, the usability, how much effort it takes to apply the system, or the user's individual perceived value-in-use of a VMP (Robra-Bissantz, 2018; Venkatesh and Bala, 2008; Venkatesh et al., 2012). Hence, the challenge is to align the early stages of the VMP concept research with possible future research gaps that focus on different questions. Then, a paradigmatic change towards interpretivistic methods could be of interest in order to enrich the VMP concept together with other stakeholders of the domain, for instance, implementers, practitioners, or educators (cf. *engaged scholarship*, (Van de Ven, 2007)). That could lead to more holistic knowledge and maturity of the design. Therefore and due to the intention to analyze an artifact in the design science context, a design-oriented research methodology should offer the tools and paradigmatic perspectives for both: this initial and more mature or different research gaps in order to create a practice-oriented, research-based VMP design. The Design Science Research Methodology (DSRM) offers a suitable framework for this dissertation. It "is a 'lens' or set of synthetic and analytical techniques and perspectives (complementing positivist, interpretive, and critical perspectives) for performing research in IS." (Vaishnavi et al., 2019, p.1) The focus of DSRM lies in producing IS design-related contributions in the form of theories, constructs, models, methods, instantiations, technological rules, and design principles (Gregor and Henver, 2013). These contributions are developed by designing innovative artifacts (e.g., an information system or a model) and their analysis of performance.

The process of reflection and abstraction then derives knowledge (Vaishnavi et al., 2019). At the same time, the multi-paradigmatic stance identified for this research in the last section, is also propagated by the DSRM (Vaishnavi and Kuechler, 2015). While the contributions of a DSRM approach may be manifold, authors emphasize the growing importance of design theories (DT) (Gregor and Henver, 2013; Gregor and Jones, 2007; Robra-Bissantz and Strahringer, 2020; Vaishnavi et al., 2019). For instance, Gregor and Jones (2007) developed a scheme to present and describe DTs. Later, Gregor and Henver (2013) approached the type of contributions by ranking them based on their level of maturity (see table 5.2). Nascent and

	Contribution Types	Example Artifacts
More abstract, complete, and mature knowledge	**Level 3.** Well-developed design theory about embedded phenomena	Design theories (mid-range and grand theories)
	Level 2. Nascent design theory - knowledge as operational principles/architecture	Constructs, methods, models, design principles, technological rules.
More specific, limited, and less mature knowledge	**Level 1.** Situated implementation of artifact	Instantiations (software products or implemented processes)

Table 5.2: Design Science Research Contributions Types (Gregor and Henver, 2013).

mature DTs are rated as the higher-level contributions. Driven by the research motivation, a mature DT of how to build a VMP for any given, reasonable context, is therefore the overall goal to which this thesis aims to contribute. But this goal is, just like most general DTs, an effort of the whole research community over a span of several years (Vaishnavi et al., 2019). The core of a DSRM approach consists of two essential parts, the design of the artifact and the design of the process, hence, how the artifact is built. Combined, they build a (nascent) design theory (Baskerville and Pries-Heje, 2010; Gregor and Jones, 2007; Hevner et al., 2004; Simon, 1996). If the research question can be confirmed, meaning it is reasonable to assume that the design of a VMP is relevant to fulfil its purpose, then the results of the studies should consequently be presented in a format that respects the DSRM conventions in order to explicitly support a design theory for VMPs. Hence, besides answering the research question, the outcomes of the studies could be stated as design principles (level 2 contribution). A design principle specifies design knowledge in a form that is accessible. As a part of a design theory (Vaishnavi and Kuechler, 2015), they are general descriptions referring to components of the design, here, of a VMP. Furthermore, a design principle is not only a description of what has to be done and what aim will be achieved by the implementation. It also states why it works, so it informs the implementer about the underlying causal mechanism (Baskerville and Pries-Heje, 2010; Gregor et al., 2020; Robra-Bissantz and Strahringer, 2020). As shown in table 5.3, Gregor et al. (2020) analyzed the anatomy of a design principle and suggest to present them using the structure and its belonging components (note that, components are sometimes explained implicitly). Moreover, they present three distinct types of design principles:

1. Design principles about **user activity**. What can the user do with a specific artifact?

2. Design principles about **an artifact**. What features should an artifact have? (e.g. the shape or function)

3. Design principles consisting of a **combination of both** and the characteristics an artifact should posses.

In addition to that, the authors distinguish four relevant, sometimes human roles that may occur in a design principle:

1. **The Implementer**, who interprets the abstract specification and applies it to the instance domain.

2. **The Recipient User**, for whom the principle shall achieve a specified aim.

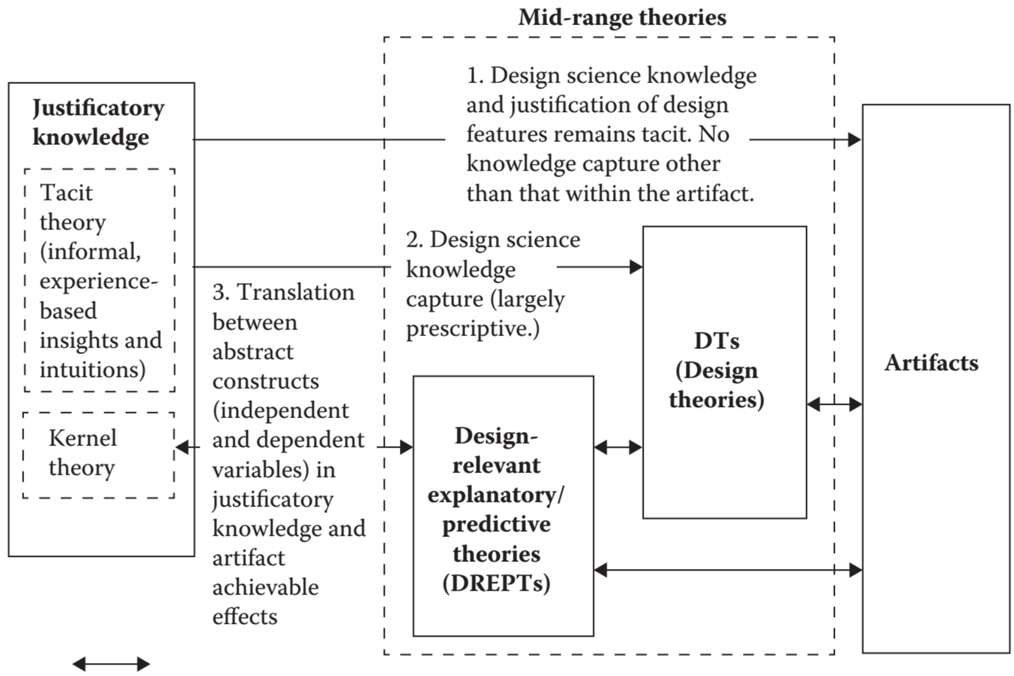
3. **The Enactor**, who takes part in a specified role to support a mechanism that aims to reach the aim.

4. **The Theorizer**, who gathers the abstract design insights from the artifacts to use them in research and future applications.

Title: Design Principle Name	
Structure	Components
For Implementer I to achieve or allow Aim A for User U	Aim, Implementer, and User
in Context C	Context (Boundary conditions, implementation setting, further user characteristics)
Employ Mechanisms M1, M2, M3.... involving Enactors E1, E2, E3,...	Mechanisms (acts, activities, processes, form/architecture, manipulation of other artifacts) Subsidiary components/artifacts that can have their own design principles
because of Rationale R	Rationale Theoretical or empirical justification for the design principle

Table 5.3: Components of the Design Principles Schema. (Gregor et al., 2020)

This dissertation will not focus on a VMP's design process since it is not considered relevant to answer the research question. However, in the younger literature there are several approaches suggesting research process models, hence, guidance on how to conduct design science research (DSR) (e.g. Peffers et al. (2007), Hevner et al. (2004) or Purao (2002)). The work of Vaishnavi and Kuechler (2015) focuses on creating design science knowledge, which is a suitable intention for this dissertation as well. They provide a framework and a process model that guide the researcher along the way of producing DSR contributions. Additionally, they suggest a range of useful patterns to conduct each phase of their process model. First, the framework shall be described, since it shows which general paths of theory development are available in DSR (see figure 5.1). There are three essential ways to create design science artifacts. All of them are capable of producing design science knowledge. The first path indicates that the artifact is developed based on justificatory knowledge but without contributing any theoretical insights. The second one implies that the underlying, justificatory knowledge (cf. Gregor and Jones (2007)) is used to derive a DT, which in turn serves as a foundation for the instantiation of an artifact. The artifact is then further improved by iterations of reflection and abstraction. The third path focuses on using any relevant kernel theory (independent and dependent variables) originating from mathematics or natural, social, or design science. It is translated into a format that allows the artifact to show the effects between these variables. This translation is then called a design-relevant explanatory/predictive theory (DREPT). The DREPTs aim to explain how and why the design works and why it is new. They can also be refined and improved by the evaluation of the artifact and can, therefore, also inform or update the kernel theory. In contrast, the DT rather focuses on the implementation, hence, what has to be built. A DREPT is more abstract than the DT, so it represents the knowledge that can be applied to multiple classes of artifacts. Summarized, the arrows indicating these three paths describe a logical process that concretes abstract, justificatory knowledge into a manifestation in the form of an artifact. The DREPTs and DTs are intermediaries to assist this process. It is important to mention that Gregor et al. (2020) referred to the DREPTs when deriving the explanatory part of their schema for design principles (the rationale R, see table 5.3). Hence, the DREPTs are a conceptual component of the newer published idea of a design principle by Gregor et al. (ibid.). So, Vaishnavi and Kuechler (2015) illustrated the rationale of a design principle (DREPT) and its description (artifact) in two different components of the framework. However, answering the research question aims to generate knowledge about the influence of the design of a VMP. This knowledge will be formulated as design principles that include the justificatory parts, hence, the rationale R as named by Gregor et al. (2020) or the DREPT, as named by Vaishnavi and Kuechler (2015).



Deduction/abduction (left to right) Induction (right to left)

Kernel Theory: Social, mathematical, and design science theories as well as natural science (e.g., physics, psychology) theories

Artifacts: Constructs, models, frameworks, architectures, design principles, methods, instantiations

Figure 5.1: Theory Development in DSR. (Vaishnavi and Kuechler, 2015)

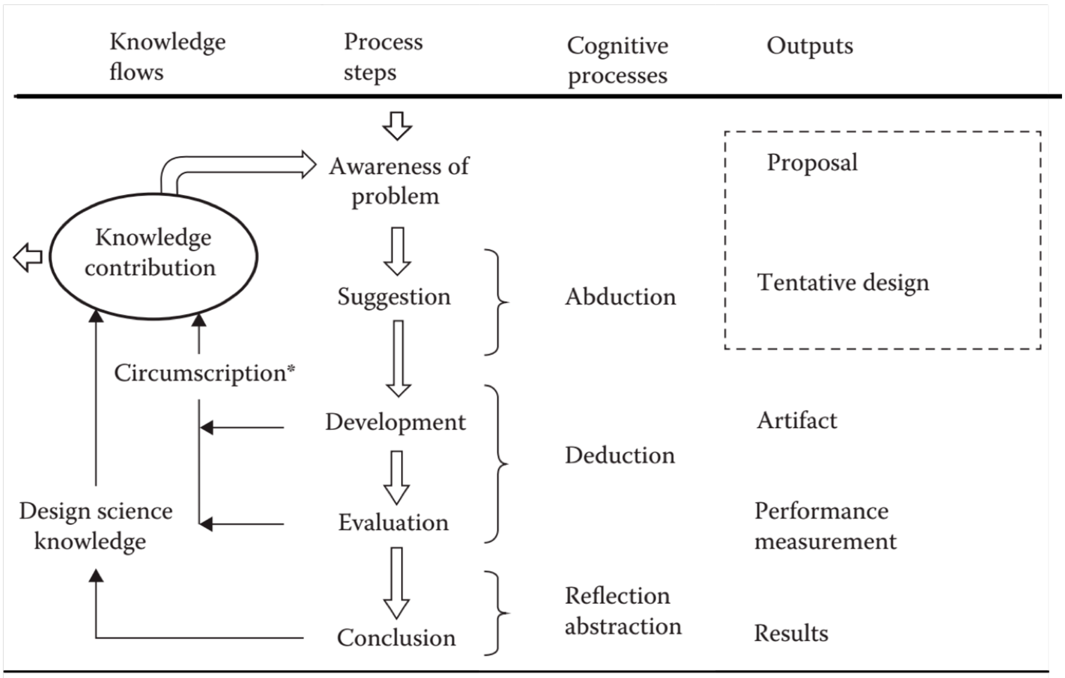
Application of the Framework

As described above, there are three general paths for generating design science knowledge. To answer the research question, the third one corresponds perfectly to the experimental evaluation of the three design-related domains identified in the literature review: The justificatory knowledge is given by the supposed neural mechanisms behind the MOL (kernel theory) and the MOL with its historical and scientific background. For example, combined with the kernel theory of the influence of immersive presence (domain: technology) on the users' memorization performance, an abductive assumption leads to a DREPT. For instance: "an immersive display facilitates the memorization performance of the user in a VMP." This statement also illustrates the derivation of an independent (immersive presence) and a dependent variable (memorization performance). The DREPT then allows to deductively implement an artifact, for instance, an instantiation or a complete design principle, as suggested by Gregor et al. (2020).

While this framework generally supports the theoretical application of DSRM to answer the research question, the DSR process model of Vaishnavi and Kuechler (2015) and its application will give a more detailed description of the exact flow of abduction, deduction, and induction to generate the design science knowledge in the form of design principles.

5.3.2 Research Model

Vaishnavi and Kuechler (ibid.) developed their DSR process model based on the one suggested by Takeda et al. (1990). The important difference is given by the highlighted and new process of DSR knowledge generation. Before explaining each phase, note that the model is designed as an optional cycle. That emphasizes the iterative nature of DSRM. Consequently, the studies in the following sections were aligned in this model, together with this dissertation. As a result, the knowledge gathered from each cycle was respected in the succeeding cycle. First, "the awareness of the problem" needs to be outlined. It may come from many different domains, like the industry or other disciplines. An interdisciplinary problem origin may also contribute to new ideas. As shown in the literature review, the VMP design problem and its relevance were derived from a wide variety of research domains. Second, the suggestion phase delivers a proposal based on the awareness of the problem. It describes a tentative design for a prototype that operationalizes the constructs of the problem. This step is described in the research question and its three design domains, and also in the studies in the later sections (i.e., visual loci are better for memorization than imaginary ones). Third, the tentative design is implemented. The instantiations are described in detail in each of the following studies (prototype sections) in section 6. The third and fourth steps in the DSR



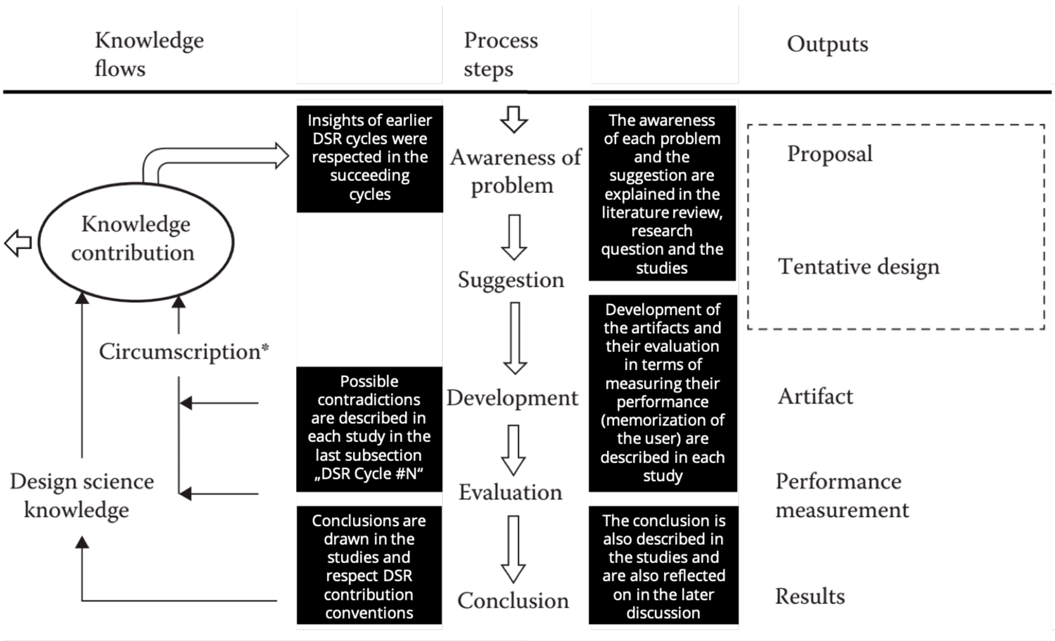
*Circumscription is discovery of constraint knowledge about theories gained through detection and analysis of contradictions when things do not work according to theory (McCarthy, 1980)

Figure 5.2: DSR cycle by (Vaishnavi and Kuechler, 2015).

cycle are characterized by optional paths that lead to an iteration of the current process. Vaishnavi and Kuechler (2015) marked them as "circumscription". Authors highlight the importance of this path: "The circumscription process is especially important to understanding the DSR process because it generates understanding that could only be gained from the specific act of construction." (ibid., p.18). The usefulness of theory or knowledge for practical concerns can only be validated by testing them. Therefore, the DSR process improves when things do not work as expected from the theory. Because now, the researcher adjusts his perspective and learns what works and what does not: through finding contradictions and solving them. Contradictions often occur in the research process, not necessarily because the theory is bad or due to misunderstandings, but rather because any knowledge base is incomplete in nature. By this process, constraint knowledge is identified, which is valuable for a deeper understanding of any domain (Vaishnavi and Kuechler, 2015).

Forth, the evaluation phase is conducted. Here the artifact is evaluated following the criteria described in the problem earlier. The papers in the section will describe in detail the specific hypotheses and their analysis. The limitations and implications for future work are also discussed. Note that study #3, besides analyzing the influence of immersion, also examines an aspect crucial to DSRM according to Hevner et al. (2004): the usefulness of the artifact. Further details are available in the paper in section 6.3. The final phase, the conclusion, either represents the end of the whole research effort or the end of a cycle. Each study that was conducted served to answer the research question and contribute to the DSR knowledge about VMPs. Therefore, each one of them represents a cycle and not the end of the VMP design research. As emphasized by Gregor and Henver (2013), Hevner et al. (2004), and Vaishnavi and Kuechler (2015), the communication of the results to the community is an important part. Each study of this dissertation was presented at major IS conferences. The results were discussed and published in the conference proceedings.

Figure 5.3 summarizes the adoption of the DSR cycle to this dissertation.



*Circumscription is discovery of constraint knowledge about theories gained through detection and analysis of contradictions when things do not work according to theory (McCarthy, 1980)

Figure 5.3: Adopted DSR cycle.

6 Research Contributions

The following subsections consist of the studies that address the research question and the three domains of design which were highlighted in section 4. Note that the papers were all double-blind peer reviewed, published, presented and discussed at major IS conferences (see table 6.1).

#	Year	Authors	Title	Outlet
1	2017	Jan-Paul Huttner and Susanne Robra-Bissantz	An Immersive Memory Palace: Supporting the Method of Loci with Virtual Reality	Americas Conference on Information Systems
2	2018	Jan-Paul Huttner, David Pfeiffer and Susanne Robra-Bissantz	Imaginary Versus Virtual Loci: Evaluating the Memorization Accuracy in a Virtual Memory Palace	Hawaii International Conference on System Sciences
3	2019	Jan-Paul Huttner, Kathrin Robbert and Susanne Robra-Bissantz	Immersive Ars Memoria: Evaluating the Usefulness of a Virtual Memory Palace	Hawaii International Conference on System Sciences
4	2019	Jan-Paul Huttner, Ziwei Qian and Susanne Robra-Bissantz	A Virtual Memory Palace and the User's Awareness of the Method of Loci	European Conference on Information Systems

Table 6.1: List of Research Contributions

Therefore, the contributions fulfilled the requirements of the Design Science Research model from section 5.3.2 by communicating and reflecting the results with colleagues and practitioners on an international scale. In order to increase the readability of the studies, each one was shortened by leaving out the introduction and the related work section, since it is always quite similar and were already given by the first sections of this dissertation. A few duplicate parts occur along the studies, for instance, how the recall accuracy was measured or particular abbreviations that were already introduced earlier. However, these parts were not removed to keep the texts as original as it makes sense. Only minor changes were performed to emphasize important parts for this thesis. Note that the semantic of the crucial parts like the theoretical background, the hypotheses, the experiment, the data and its analysis, as well as the interpretation and discussion, were not altered.

6.1 Study #1: Supporting the Method of Loci with Virtual Reality

6.1.1 Theoretical Background & Hypotheses

In 2016, Jund et al. conducted an experiment to explore the impact of the users' frame of reference on the memorization performance in virtual environments. To do so, they chose the MOL as learning technique and found out that an ego-centric frame outperforms an allo-centric frame to offer the user spatial cues. Moreover, the authors strongly suggest the use of virtual reality (VR) for the application of the MOL. Due to the rich spatial cues, they identify an immersive VR environment as the perfect technology for this use case (Jund et al., 2016).

Witmer and Singer describe immersive presence (also immersion) as the perception of being in a certain location although one is physically in another one (Witmer and Singer, 1998). It could be shown that immersive presence is a crucial factor to perform successfully in virtual environments. It reduces the cognitive burden (Agarwal and Karahanna, 2000) and supports cognitive processing (Ragan et al., 2012), which fosters the task performance (Witmer and Singer, 1998). Moreover, Liu et al. (2014), Bredl et al. (2012) and Dede (2009) found that the perceived enjoyment, learning and engagement are also positively influenced by the level of immersion. The user's memory performance concerning virtual objects and the spatial layout are fostered as well (Lin et al., 2002; Mania and Chalmers, 2001). In 2010, Ragan et al. (2010) performed a study to analyze the influence of different levels of immersive presence on procedural memory. Participants had to fulfil procedural tasks in a virtual environment. The virtual world was presented using different devices to generate different levels of immersion. Like sorting or rearranging simple objects on a table. Later, they had to repeat this task in the real world. The study was motivated by the idea, that a higher level of immersion results in more spatial cues, which improve the users' spatial perception of the environment. However, they found a positive correlation between an increasing level of immersion and the memory performance. That implicates, that a higher immersion facilitates the association between a spatial cue and an information. This is the main principle of the MOL. Therefore, a head-mounted display (HMD), which generates a higher level of immersion (Ragan et al., 2010), should improve the performance of the virtual MOL (vMOL) (Jund et al., 2016) in terms of learning success and actual use of the MOL. The learning success should increase as the process of building an association between a locus and an information is easier. The actual use of the vMOL should increase as the users' cognitive burden in a more immersive environment is lowered due to better spatial cues. Hence, using the virtual reality environment as a memory palace should be easier. Thus, the evaluation of these two measures, the learning success and actual use, will be the central aspect in this investigation. The learning success or memorization performance is measured as the accuracy of the recall ability. Legge et al. (2012) measured the recall accuracy with two scores. These scores are the proportion of words each participant is able to recall after memorizing a list of eleven words. The first one, the strict score, measures how many words the participant was able to remember, considering the correct position. For instance, if a list consists of the words fish, spoon, table and the participant enters the words table, spoon, fish then the strict score would be 0.33 as only the word spoon is correct and in the right position. The second score is calculated in a more lenient way. The lenient score also measures the percentage of the words that could be recalled, but disregards the position. Following the example above, the lenient score would be 1.0 or 100% as every word in the list could be recalled. The words in the lists were not chosen randomly. The authors found in their study, that high imaginable words (words that have a high score of concreteness, e.g. "tree") are easier to remember than words with a low concreteness (e.g. "wisdom") in general.

In this study, the variance of the concreteness were not part of the research approach. Therefore, the words that were used here, are all of a high concreteness. The source of those words is a list of Kanske and Kotz (2010). They conducted a study with a total of 64 participants to rate, amongst other word properties, the concreteness of approximately 1000 words. However, the word lists in this investigation were created in a way to ensure an equal level of concreteness. Finally, Legge et al. (2012) used a questionnaire to determine the actual use of the vMOL. It was measured as the compliance rate. This rate indicates whether and how strong each participant was compliant to the instructed vMOL. It is defined by the number of lists a participant was able and willing to memorize and recall by applying of the MOL. A participant was regarded as compliant if s/he used the MOL for at least 50% of the lists (ibid.). However, due to the theory and research question described above, the following three hypotheses will be investigated.

H1a: Using a HMD to apply the vMOL will result in a higher strict score than applying the vMOL with a computer screen.

H1b: Using a HMD to apply the vMOL will result in a higher lenient score than applying the vMOL with a computer screen.

H2: Using a HMD to apply the vMOL will result in a higher compliance rate than applying the vMOL with a computer screen.

6.1.2 Experimental Design

An experiment was performed to analyze this research approach. The experimental design, including its procedure and the measurement of the learning success, is closely aligned to the study performed by Legge et al. in 2012 as its design fits the research question in this study (ibid.).

6.1.2.1 Participants

A total of 78 unpaid students took part in the experiment. They were aged 17 to 29 (mean = 23,79, 21 females). Participants were required to have German as their mother language as the study involved the reading and writing of German words. The students were invited to the experiment and could subscribe anonymously. About 55% of the participants reported to have at least heard of the MOL in advance, but none of them uses it regularly or knows exactly how it works. Note that the participants, who had at least a little knowledge about the MOL, were almost evenly distributed between the experimental groups.

6.1.2.2 Technology

As mentioned above, the level of immersion should have a positive influence on the vMOL effectiveness. In order to increase the user's immersive presence, participants of the virtual reality group were equipped with a HMD to explore the virtual reality. The applied HMD is a system that needs a smartphone that serves as the display, while two lenses in the HMD generate a stereoscopic effect. This effect gives the user the illusion of spatial depth. Hence, the user optically perceives the virtual environment in three dimensions. The virtual environment was developed with the game engine Unity 3D (version 5.5.0) and is closely aligned to the virtual apartment that was used by Legge et al. (2012). Figure 6.1 illustrates the bird and the first-person view of the virtual apartment. Every room has several loci (e.g. plants, tables, chairs, cupboards or images) that can be used to establish a mental association between them and the learning content. Hence, this apartment was the virtual environment thought to serve every participant as the template for their memory palace. In order to ensure a smooth and fluent virtual experience,

Figure 6.1: Bird and First-Person View (Study #1)

the smartphones' hardware performance was good enough (Google Nexus 6P, last generation of Google's high end smartphone). The same applies to the type of computer screen that was used for the other set of participants. The detailed procedure of the experiment will be explained in the following section.

6.1.2.3 Procedure

Participants were randomly assigned to one of two groups, the computer screen and the virtual reality group. All participants performed under the same conditions except the medium that was used to present the virtual environment. Table 6.2 shows the sequence of the essential elements in this experiment. First, every participant was given a few minutes to become confident in the navigation in both devices (computer screen first, then HMD). The practice in both media was thought to ensure that the practice environment and medium did not affect the participants' performance in the later phase in any way. However, a simple, virtual practice room was implemented for the computer screen and the HMD device. This virtual room was empty and therefore did not contain any loci. Participants were told to get familiar with the navigation in the virtual environment. The integrated keyboard and an external mouse were used for navigating in the computer screen environment. The user was able to walk by using the arrow keys while the mouse was used to look around. In the virtual reality environment, the user's physical head movement was tracked by the smartphone in the HMD and then translated directly into the virtual environment. The gamepad was used for walking. After a few minutes, when the particular participant confirmed to be confident in the navigation s/he was asked to remember and reproduce a practice list of words. The list was presented on a computer screen screen and contained eleven words. This practice task was given to ensure that each participant understood the procedure correctly which was important later in the recall phase. All lists that were presented followed the same protocol used by Legge et al. (ibid.). Hence, each word in a list was shown solely for 5000 milliseconds in the center on a white background.

	Practice	**Recall**
1	Instructions for the notebook VMP	Exploring the VMP (notebook or VR)
2	Navigation for the notebook VMP	Instructions how to apply MOL
3	Instructions for the VR VMP	Serial recall phase: 5 lists, 11 words each
4	Navigation in the VR VMP	
5	Practice list for the recall phase	

Table 6.2: Procedure of the Experiment (Study #1)

An inter-stimulus break of 150 milliseconds divided the presentation of each word and its successor. The participants' task was to remember the list and reproduce it by entering the words in a single web based form field, one after another and if possible in the same order. The test person entered the remembered word and pressed enter to confirm the input. If s/he could not recall the word at a certain position, there was a skip button implemented. By clicking this button, the form field was marked as empty at this position and the participant could enter the next word. This recall phase was limited to 120 seconds, so if a participant needed more than 120 seconds, the form automatically saved every word s/he entered until this point. Participants did not receive any information about how many or which words were already entered or how much time they had to enter the lists. After completing the practice list task, the practice phase was finished and participants were introduced to the virtual environment. As described in the related work, this virtual environment should serve them as a template for their memory palace. Depending on the group (computer screen or VR), they either received a computer screen or a HMD. Participants had a maximum of five minutes to explore the virtual apartment. After that, they received a written instruction on how to use the MOL. This instruction was the same one that was used by Legge et al. and is based on the description of Yates (Legge et al., 2012; Yates, 1999)(see Appendix A). It was translated into german, as the test persons were predominantly German students. After participants were informed how to apply the vMOL, they were presented five lists of eleven words each. The procedure was the same as in the practice phase, but this time s/he had to remember the words by building an association between them and the loci in the virtual apartment. Finally, every participant was given a questionnaire to report, amongst others, the demographic information and her/his compliance rate.

6.1.2.4 Data Analysis

The data analysis was conducted with the open source software R (version 1.0.136). The two-sampled Welch' t-test and an exact chi-square test (Fisher-Yates test) were used to analyze the differences of means and the differences of the distribution of compliance rates between the two groups. The Welch' t-test was preferred against the students t-test due to its robustness against unequal sample sizes (Ruxton, 2006; Welch, 1947). Similarly to Legge et al. (2012), an alpha level below

0.1 was considered as a trend effect (p<0.1). Also, the analysis was conducted on all participants and again for the "compliant only" subset. Therefore, results will be shown for these two groups to show whether the learning success (accuracy) differs between them. It is expected, that the "compliant only" subset will show better results due to the hypothesized superiority of the MOL.

6.1.3 Results

In the following the data is statistically analyzed and interpreted to illustrate findings and relevant questions for future research in the domain of the vMOL.

6.1.3.1 Accuracy

The analysis of the accuracy involved the measurement of the strict and lenient scores of all participants. As described in the experimental design, these scores were measured using lists of highly concrete words. To determine the average scores for each group (computer screen and VR) and participant, each score was calculated as the mean over the five lists. So, these means were considered as the overall strict or lenient score for a particular participant. For instance, if a participant reached the strict scores 0.30, 0.70, 0.30, 0.30 and 0.40 for the lists one to five, his overall strict score would be 0.40. These means of strict and lenient scores were then used to compare the accuracy of both groups. Tables 6.4 and 6.3 give an overview of the means of the strict and lenient scores.

	Strict Score		
	Computer screen	**Virtual Reality**	**Difference between groups**
All participants	0.4327	0.4880	+0.0553
Compliant only	0.4293	0.4923	+0.063
Difference between compliance	-0.0034	0.0043	

Table 6.3: Analysis of the Strict Score (Study #1)

The strict score ranges between 42% and 50%, while on average the virtual reality group achieved better results than the computer screen group (approximately 5 to 6%). However, t-tests did not show a significant difference of means, neither for

	Lenient Score		
	Computer screen	Virtual Reality	Difference between groups
All participants	0.6495	0.7186	+0.0691
Compliant only	0.6651	0.7218	+0.0567
Difference between compliance	0.0156	0.0032	

Table 6.4: Analysis of the Lenient Score (Study #1)

all participants, nor for the compliant only subset of the groups (all participants: df=75,84; p-value=0,2353 and compliant only: df=62,26; p-value=0,2051). The lenient score lies between 64% and 73%. Again, the virtual reality group performed better than the computer screen group on average (approximately 5 to 7%). T-tests showed a trend effect for the set of all participants on a level of p<0.1 (all participants: df=70,59; p-value=0,094 and compliant only: df=53,15; p-value=0,2092). Except for the strict score in the computer screen group, the difference of the scores between the compliance levels implicates a small improvement on average. Hence, hypotheses h1a cannot be confirmed. Hypotheses h1b cannot be confirmed either as only the all participants analysis showed a trend effect (p<0,1).

6.1.3.2 Compliance Rate

As mentioned earlier, the compliance rate is the number of lists each participant memorized and recalled by the use of the MOL. It was measured by self-assessment while participants were considered compliant if they applied the MOL for at least 50% (three lists). Results are shown in table 6.5. Analysis shows that the

# of Compliant lists	0	1	2	3	4	5	Total	Compliance
Computer screen	1	3	5	10	14	7	**40**	**77,5%**
Virtual Reality	0	1	0	11	6	20	**38**	**97,4%**

Table 6.5: Frequency Distribution of Compliant Lists (Study #1)

participants of the virtual reality group were significantly more often compliant compared to the computer screen group (computer screen: 31/40, VR: 37/38).

The exact chi-squared test resulted in a strongly significant difference ($p<0.01$) between the two groups (p-value=0,0021). Therefore, the hypothesis h2 cannot be rejected at this point.

6.1.4 Discussion & Conclusion

The approach in this study was to evaluate the possible improvement of the vMOL. Multiple studies were found that promote the positive effects of immersive presence on important factors like memory performance (Bredl et al., 2012; Dede, 2009; Ragan et al., 2010). Consequently, two groups were instructed to apply the vMOL, while one group was told to use a device (HMD) that generates a higher level of immersion. Two central performance indicators were tested: the accuracy and the actual use or compliance rate. It was hypothesized, that the group with the HMD achieved better results in the accuracy and compliance rate. The analysis of the data does not fully support the expected effects. However, it was shown, that the learning success substantially varies between the computer screen and the virtual reality group. All the average scores (strict and lenient) in the virtual reality group are approximately 5 to 7% higher than those in the desktop group. This indicates a trend promoting the advantage of the virtual reality MOL. A possible reason for the accuracy difference might be that the level of immersion was not high enough in the virtual reality group to show significant effects. In this study, the level of immersive presence was increased by the use of a HMD. Other aspects, that help to improve the immersion should also be considered. For instance, some participants commented that the feeling of being entirely in the virtual world would increase with a sound feedback like footsteps or other noises that are typical for an apartment. According to Dede (2009), sensory cues are a key factor for immersive presence. Therefore, auditory cues would be a reasonable feature to increase the level of immersion (Dinh et al., 1999). Of course, the difference in accuracy levels might also be caused by the fact that participants in the VR group were significantly more compliant. As explained in the introduction, the MOL improves the memorization performance. Therefore, the factors recall accuracy and compliance rate are most probably not independent from each other.

However, the exact correlation between the level of immersion, the compliance rate and the accuracy should be investigated in future studies.

Another limitation is given by the homogeneous group of participants (students only) and a majority of male participants, and of course, an increased number of compliant participants could help to find more significant results in this area. It is certainly necessary to invest further research in the application of the virtual reality based MOL, but results in this study indicate a relevant and unused potential lying in this approach. For future research, an improvement of the immersive experience by integrating multi-sensory cues is suggested, as wells as an investigation of its statistical correlation to the factors compliance and recall accuracy. Nevertheless, Legge et al. (2012) emphasized that the compliance rate is especially important for researchers as the number of compliant participants of an experiment is crucial for reliable research results. Therefore, the application of the vMOL with a high immersive virtual reality is encouraged at this point.

6.1.5 DSR Cycle #1

Study #1 represents the first DSR cycle and investigated the influence of immersive presence on the memorization performance and the compliance rate. While the compliance rate seems to be positively impacted by a higher level of immersion, the memorization performance did not show any significant differences. Hence, the question is, why is that? As described by Vaishnavi et al. (2019), contradictions in the DSR progress are an important part of the approach to learn more about the subject, and to improve the design. Therefore, the circumscription in this cycle is given by the insight, that the level of immersion did not leverage the recall accuracy as expected. A possible reason for that could be that the difference of immersion was not high enough as described in section 6.1.4. Another possible cause is an effect that may have facilitated the memorization process of the participants. The task was to memorize five lists of words, hence these words were presented as "chunks" (adapted from (Legge et al., 2012)). The memorization of "chunks" is easier than memorizing the terms on its own (Bor et al., 2003; Dowling, 1973; Lindstromberg and Boers, 2008a,b). This could have facilitated the task in both

MOL conditions in a way that eliminated the effect of the immersive presence on the memorization performance. Consequently, the upcoming studies will implement a different approach to avoid this possible bias. Furthermore, the use of a HMD seems to have at least a positive impact on the compliance rate, which is why future studies will also be conducted in the VR. The next study investigates the design domain "degree of visualization" by comparing imaginary (or external) loci with visualized ones.

6.2 Study #2: Imaginary versus Visualized Loci in a VMP

6.2.1 Theoretical Background & Hypotheses

The variety of the the VMP concepts was highlighted and explained in sections 3 and 4. In order to investigate the role of the degree of visualization of the elements of a VMP, this study focuses on the loci-design. Table 6.6 summarizes the different design features that were implemented by related experiments and concepts.

	3D	Image	Text	External (imaginary)	Animated	Audio
Hedman & Bäckström			X			
Mann et al.	X		X			
Jund et al.		X				
Fassbender & Heiden	X	X			X	X
Legge et al.			X	X		

Table 6.6: Overview of the Loci Design (Study #2)

Clearly, the loci design of past studies varies substantially. This might be due to the fact that, besides others, the traditional MOL is performed completely in mind. Earlier studies that transferred the MOL into a virtual world context did not explicitly evaluate to which degree the method should be performed in mind, especially regarding the conceptualization and design of the loci. Since the traditional MOL heavily relies on the idea to mentally establish an individual, unusual and unique visual association between an item and a locus, it seems questionable whether a predefined and integrated locus is better suited for the memorization process than a completely mind-based locus. Therefore, this study aims to answer the research question whether in a VMP, the concept of imaginary or visualized locus leads to better user memory.

In the dual coding theory, Paivio and Lambert (1981) assert that human cognition and memory depend heavily on two connected neural systems. Despite their interconnected design, they are capable of working independently. While one system processes non-verbal information, the other one converts verbal input. However, based on the interconnection between them, a neural interpretation of one system is able to produce an association to representations in the other one. Malaga (2000) gave an example, stating that if a picture is named to a subject, certain images may appear in his/her visual mind while reading a particular word. Furthermore, studies have revealed an improvement of subjects' recall accuracy if pictorial and lexical stimuli were used simultaneously (Paivio, 2014). This theory is also supported by other authors, who describe a superior memorization performance achieved with the help of a combination of text and images over either one of them solely (Fleming, 1979; Shepard, 1967; Standing, 1973).

Based on this theory, an experiment was conducted to investigate the effectiveness of imaginary versus virtual representations of the to-be-remembered items. Therefore, two prototypes of VMPs were implemented for virtual reality devices. The first one is equipped with virtual loci, the second one only offers text-based items so the users have to create their loci in mind. A more detailed description will be given in section 6.7. Referring to the design domain of "degree of visualization" (cf. section 4), the question of interest is whether the visual integration of the loci in the virtual world facilitates the association and memorization process compared to a protocol which demands the user to build the loci exclusively in mind (see Legge et al. (2012)). Following the dual coding theory, a locus which is a combination of an image and a naming word should establish a stronger association than a text-only locus. Consequently, the participants' recall accuracy should be superior in the image-text group.

The measurement of the recall accuracy is based on the scores introduced by Legge et al. (ibid.). They used two different approaches to indicate the proportion of items a participant was able to remember. The strict score reflects how many words a participant was able to recall in order. For instance, a list consisting of the five items chair, pen, table, book and window would be presented to the subject. If s/he then enters pen, chair, table, window and cook the strict score would be 0.2 as only table was entered at the correct position. The second score, the lenient score, measures the overall proportion of words that could be recalled, ignoring the correct position. Considering the strict score example, the lenient score would be 0.8 since only the last item cook is not in the list. Relating to the supposed superior influence of an image-text locus over a text-only condition, the following hypotheses are derived.

H1: Memorizing the items by the use of visual loci will result in a higher strict score than by the use of exclusively mental loci.

H2: Memorizing the items by the use of visual loci will result in a higher lenient score than by the use of exclusively mental loci.

6.2.2 Experimental Design

The following sections describe the experiment's central aspects, i.e. the participants, the technology that was used, the experimental procedure and the VMPs. As mentioned in the last section, the recall accuracy was measured using the strict and lenient score calculation. However, the list of words that were presented to the participants was not chosen randomly. First, according to Bellezza (1981) the length of the item list for a MOL investigation should be longer than ten words, otherwise the effectiveness of the MOL would not be noticeable. Hence, the list that was used in this study had a length of 40 words as suggested and applied by Ross and Lawrence (1968). Moreover, the items were chosen to lessen the mental effort for the mostly beginner level participants. Legge et al. (2012) stated in their study that words of a high concreteness, i.e. words that are easy to imagine, are easier to remember in general than those with a low concreteness. For instance, a word with a high level of concreteness would be spoon, while a term like arrogance is more abstract. Hence, the words the participants had to memorize in this experiment were all of a high concreteness. Kanske and Kotz (2010) evaluated a list of approx. 1000 German words with the help of 64 participants. They rated a variety of the word norms, amongst others, the level of concreteness. The items in this experiment were taken from this list. However, two groups were instructed to apply the vMOL in the VMPs. The loci in each VMP were thought to be memorized either as text-only or image-text combination in a predefined condition. Section 6.2.2.2 is going to give a more detailed description of the design features.

6.2.2.1 Technology

As indicated by Jund et al. (2016) a higher level of immersion should positively influence the virtual MOL experience. Several studies refer to the beneficial effects that high immersive presence has on crucial factors (e.g. cognitive burden and processing, enjoyment or engagement) to successfully memorize and learn (Agarwal and Karahanna, 2000; Bredl et al., 2012; Dede, 2009; Lin et al., 2002; Liu et al., 2014; Mania and Chalmers, 2001; Ragan et al., 2010; Witmer and Singer, 1998). Immersive presence is experienced if one is perceptually in a location although one is not physically. Furthermore, a promising effect of immersive presence in the context of a VMP was investigated and promoted by Huttner and Robra-Bissantz (2017). Hence, the VMPs were developed for a head-mounted display (HMD), respectively as a virtual reality environment. HMDs generate a higher immersive presence than e.g. a computer screen (Ragan et al., 2010). In addition to that, virtual reality is a promising technology for educational purposes. Especially the Google Cardboard technology offers a low-priced opportunity for the majority of the society (Martín-Gutiérrez, 2017). In this concept, the smartphone's display generates a stereoscopic camera perspective which is focused by two lenses in the actual HMD. Due to this effect, the user perceives the virtual world in three dimensions. Therefore, the subjects were equipped with a HMD system that uses a smartphone as a display. To walk in the virtual environment, participants could use a gaming controller, which was connected wirelessly via Bluetooth to the HMD. Furthermore, participants were given a swivel chair so they could "look around" by turning around in a seated position as the head movement was tracked by the HMD and transferred into the virtual environment.

6.2.2.2 Prototypes

As described, navigating in the VMPs was done by using the gaming controller and the head movement. In order to ensure that participants adopted this way of walking through the VR, each participant had to pass a training level. After finishing their training, they were "transported" into the actual VMP to start the

Figure 6.2: Locus in the Image-Text VMP (Study #2)

memorization phase. Not only the VMPs, but also the training levels differed between the two groups. Figure 6.3 shows the locus of the VMP of the image-text group (Tür = door).

Both VMPs were designed as an apartment and, as stated earlier, only differed in the presentation style of the items participants had to memorize. The image-text VMP had the loci integrated at a fixed position as seen in figure 6.3. A fixed circle in the center of the users' field of view served as a selection tool. Participants had to look at a locus and push a button on the gaming controller to reveal the item. In the first place, each locus was only marked as a square with a question mark on it. Only then were the specific word and image uncovered. Each locus was visible for five seconds, a time frame that was adopted from Legge et al. (2012). After that, the locus disappeared. This was the time frame participants had to memorize the item at the specific locus. In contrast to the image-text group, the text-only VMP only contained the items as a text and not fixed to a certain locus. Hence, participants had to imagine placing each item at a certain place. Again, each item was presented for five seconds and disappeared afterwards. By pushing a button on the gaming controller, the next item appeared in the users' field of vision. Note that the order of the items was the same in both conditions. The architectural design of the image-text VMP ensured that participants had to follow a predefined walking pattern. Summarized, the two presentation styles of the loci were directly adapted from earlier studies with the intention to evaluate, in a first step, which approach works better: the imaginary loci that were used by Legge et al. (ibid.) or the visually enriched loci that were integrated in the virtual worlds and implemented by other studies (Fassbender and Heiden, 2006; Jund et al., 2016; Mann et al., 2017). Additionally, a routine was implemented in both VMPs to measure the participants' activity in the VMP. Therefore, the system recorded the walking distance and the head rotation of the user as well as the time (seconds) s/he spent in the VMP. Results and possible implications are later presented in section 6.2.3.

6.2.2.3 Participants

In total, 60 undergraduate students, mostly majoring in technically oriented fields of study, participated in the experiment. No monetary compensation was provided. German was required to be the first language of the participants as the procedure needed them to read, understand and write lists of German words. Due to the experimental procedure, it was possible that participants suffered from motion sickness. For instance, this effect is likely to happen if a user experiences a delay of the visual perception in the HMD compared to her/his real head movement (Hettinger and Riccio, 1992). In this case, the ability to focus on the virtual world and the level of immersive presence is weakened (Witmer and Singer, 1998). Nine of the students reported that due to motion sickness they were not able to concentrate on the task. Hence, these participants were removed from the data analysis leaving a total of 51 datasets (Group 1: 23, Group 2: 28). The test subjects were aged between 19 and 32 (mean = 23.73, 21 females). About 11% of the participants had prior knowledge of the MOL and stated occasional use. These students were almost evenly distributed among the two groups.

6.2.2.4 Procedure

To avoid a self-selection bias, the participants were randomly assigned either to the image-text or the text-only group. All of the subjects took part under the same conditions, with the exception of the VMP. Figure 6.7 illustrates the five phases each participant had to pass. In the first phase, participants were given instructions on how to apply the vMOL. Of course, these instructions differed in terms of the description on how the items will be presented. In the following phase, participants put on the HMD and were handed the gaming controller. Before they could start the memorization phase in the VMP, the training level was loaded so the subjects could become confident with the navigation and handling in the virtual reality. As described in section 6.2.2.4, the virtual environment switched automatically to the VMP as soon as the participants completed the training task. In the third phase participants started to explore their specific VMP and navigated through the rooms to find and memorize the loci. Note that the memorization phase had no time limit to avoid setting the subjects under a pressure of time. The fourth phase started after the participants finished exploring all of the 40 loci in the VMP. Here, they were presented to a website that was developed to save the test subjects' input. This web interface was designed closely to the descriptions of Legge et al. (2012). Hence, it was a blank, minimalistic page containing a single text field and two buttons.

	Group 1 (image-text)	**Group 2** (text-only)
1	Instructions for the image-text condition	Instructions for the text-only condition
2	Training in the image-text condition	Training in the text-only condition
3	VMP for the image-text condition	VMP for the text-only condition
4	Recall	
5	Questionnaire	

Table 6.7: Procedure of the Experiment (Study #2)

One button was offered for the input confirmation, the other one was a skip button. If a participant did not know which item was next in order, s/he could simply skip the current position. Finally, in the last phase the questionnaires were handed out to acquire the sociographic information.

6.2.3 Analysis & Results

In order to prepare the data for the statistical analysis, the following revision was performed. As described earlier, the scores were calculated by the amount and order of words the participants were able to recall. If necessary, these words were corrected afterwards in cases of spelling mistakes and wrong pluralization, since all of the terms were originally presented in singular form (e.g. spoons or sppoon were corrected to spoon, if and only if the mistake or pluralization was obvious and did not alter the meaning of the word). The statistical analysis was conducted using the open source software R (version 1.0.136). Table 6.8 gives an overview of the means of the relevant results. Note that as mentioned earlier, the activity is also part of the results (head rotation, walking distance and time spent in the VMP). The rotation was measured as the accumulated degree of head rotation during the memorization phase in the VMPs.

	Group 1(image-text)	**Group 2**(text-only)
N	23	28
Strict Score	0.3109	0.1107
Lenient Score	0.7924	0.6759
Time (s)	694.1	709.2
Rotation	9316	6241
Meters	277.9	345.2

Table 6.8: Descriptive Data (Study #2)

The evaluation of the hypotheses H1 and H2 was performed by analyzing the central tendencies in the data samples of group one (image-text) and two (text-only). First, the histograms of the distribution of the strict and lenient scores in both groups were considered. Significant results in the Shapiro-Wilk test confirm that all four data samples are very likely non-normally distributed, so the p-values for the strict score are 0.0017 (group 1: image-text) and 0.0001 (group 2: text-only). The p-values for the lenient score are 0.0253 (group 1: image-text) and 0.0084 (group 2: text-only). Due to the non-normal distributed data, both hypotheses were evaluated by two-sided Mann-Whitney U tests. A significance level below 0.1 was considered as a trend effect, while values below 0.5 and 0.1 were seen as significant. The mean value of the strict score of group 1 (image-text) is 0.31 and the mean value of group 2 (text-only) is 0.11. Results of the Mann-Whitney U test show a significant difference on a level below 0.01 (p-value=0.008). The means of the lenient scores are 0.79 (group 1: image-text) and 0.68 (group 2: text-only).

Again, the difference is significant on a level below 0.05 (p-value=0.029). The data shows that the image-text group achieved higher scores than the text-only group. The difference between the lenient scores is about 11% and is approx. 1.17 times higher in the first group. The strict score in the first group is approx. 2.81 times higher than in the second group (difference approx. 20%). Both tests showed significant differences between the central tendencies of the strict and lenient scores (at least $p<0.05$). Consequently, the data supports the hypotheses H1 and H2. As mentioned in the description of the procedure, the prototypes also measured the time (in seconds) that the participants spent in the VMP. This analysis is intended to ensure that the results are not skewed by a group that spent significantly more or less time in the VMP. Again, histograms and Shapiro-Wilk tests were considered and indicated the time being normally distributed (group 1: $p=0.8477$, group 2: $p=0.1802$). Therefore, Welch's t-test was performed to reveal possible differences of means (group 1: 649.1s, group 2: 709.2s). This t-test is robust against unequal sample sizes (Ruxton, 2006; Welch, 1947). Results indicate no significant difference between the groups ($df = 48.78$, $p=0.8091$). Hence, the time the participants spent in their prototypes did not differ on a significant level. Therefore, the time is not considered as an independent factor that influenced the difference of the strict and lenient scores in this case. Another noteworthy effect was identified performing an analysis of correlation (Pearson). In contrast to the image-text group, the lenient and strict scores of the text-only group correlate positively with the intensity of the users' head rotation (level 0.4, $p<.05$). This might support the idea behind the external vMOL. More precisely, the text-only treatment probably requires more activity in the sense of searching an adequate locus by moving around the head. Hence, a positive correlation between activity and the recall accuracy possibly predicts the compliance of the participants to the MOL protocol, especially in a text-only treatment.

6.2.4 Discussion

As seen in the previous section, the data analysis supports the hypotheses H1 and H2. This indicates that the combination of images and text also leverages the recall accuracy in the context of a VMP. The difference of the lenient scores (11%) between the groups is certainly noteworthy. However, the strict score improved more clearly by the factor 2.81. This effect might be explained by the design of the prototypes. Since the image-text VMP had fixed loci, the text-only participants had to choose the loci on their own. This design gave the students the opportunity to create their loci in a manner that did not follow a certain order if one walks mentally through the VMP. Nevertheless, subjects were instructed to memorize the items in order and the analysis implies a superior effectiveness of the image-text concept over the text-only VMP.

6.2.4.1 Limitations & Future Research

At this point it is important to note that future studies could refine the experimental design and reduce the difference of the treatments between the two experimental groups in order to evaluate the users' interaction with the loci in a more detailed manner. For instance, putting the text-only items at the same places as the image-text items would align the presentation of the loci between the experimental groups. Alternatively, one could present the image-text loci at the center of the screen and therefore without a fixed position in the virtual surrounding. Hence, the process of associating the item with a certain place would happen completely in the user's mind in both settings. These modifications would reduce the difference of the treatments between the two experimental settings. In the first case, both groups would have a predefined route and in the second case both groups could freely choose their preferred path of loci. Furthermore, one could implement a feature that allows the participants to select the place where s/he wants to put the items. This way, the act of self-choosing the exact location, which is a central part of the traditional MOL, would be enabled in both groups as well. So, future prototypes and studies should evaluate explicitly how the loci design and the degree of interaction helps the user to memorize the to-be-remembered items. As shown in section 6.2.1, a variety of different loci have already been implemented, integrated in the virtual world and enriched with other media features like sound, animations or interactivity. It is necessary to evaluate how cognitive theories can help to find design principles for highly memorable loci for VMPs. This study was mainly conducted with technically oriented students in their mid-twenties. Therefore, further investigations would certainly profit from a wider range of professions and age. The factors creativity and spatial sense might be relevant independent variables when participants have to use their mind to establish mental representations of the loci in a spatial context. Measuring and analyzing these factors in a VMP setting could reveal relevant insights for the potential target group and future VMP concepts. Referring to Legge et al. (2012), they suggested to find appropriate ways to measure the compliance of the participants with the vMOL protocol. This approach shall also be outlined at this point. Since the compliance is an important factor when it comes to interpreting the analysis results, unfortunately a sophisticated method for the measurement is yet to be developed.

6.2.4.2 Conclusion

The results support the theory, that the dual coding theory also applies in the context of a VMP. It could be shown, that referring to earlier studies, the concept of visualized loci outperforms the text-only loci for the memorization process. Hence, in a next step it would be interesting to evaluate other, more complex types of loci, enriched with multimedia cues, animations or interactive behavior.

6.2.5 DSR Cycle #2

The second DSR cycle illustrates that the degree of visualization, here demonstrated by evaluating two different concepts of loci-design, likely influences the users' ability to memorize the to-be-learned items in a VMP. In contrast to the first DSR cycle, no contradictions occurred. The hypotheses could not be rejected and support the theory. Hence, the concept of visualized loci was adapted in the succeeding cycle.

6.3 Study #3: Recall Accuracy leverages the Perceived Usefulness & Immersion facilitates Recall Accuracy

6.3.1 Theoretical Background & Hypotheses

As seen in the earlier sections, prior research already investigated many crucial aspects for the concept of a VMP. Nevertheless, the user's opinion towards the virtual MOL was not part of the studies yet. Especially if a research stream focuses on practical solutions (e.g. by the DSRM), the users' perceived usefulness (PU) of the artefact is a central component (Baskerville et al., 2018; Kilduff et al., 2011; Peffers et al., 2007). Since the main purpose of a VMP is to improve the users' memorization performance, the hypothesized effect is a positive influence of the recall accuracy on the users' PU. In this study, the PU is measured using the well-established latent variable PU of Davis' Technology Acceptance Model (TAM) from 1989. He described PU as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1985). Hence, the original questionnaire items aim to evaluate the technology acceptance of a an information system in a work context. Therefore, in this experiment the items of the constructs were changed to the context of the VMP and the educational setting. The memorization performance is measured using the scoring system introduced by Legge et al. (2012). Their rating of the memorization performance consisted of two different scores, the strict and the lenient score. The strict score reflects how many terms a participant was able to recall in the correct order. The lenient score simply calculates as the percentage of correct recalled terms, ignoring the order. For instance, the participant is presented a list consisting of the five the fork, table, apple, spoon and smartphone. Then, if the participants' recalled list would be fork, table, spoon, apple and tablet, the lenient score would be 0.8 since only smartphone was missing. A more detailed description of how the strict score was calculated is given in section 6.3.3 due to the more complex calculation and the analysis related importance. However, the first two hypotheses are derived as follows:

H1: The users' achieved lenient score (short term) significantly predicts a positively correlated Perceived Usefulness

H2: The users' achieved strict score (short term) significantly predicts a positively correlated Perceived Usefulness

Another aspect that was already investigated to some degree is the factor immersion, respectively its influence on the memorization performance in a VMP (cf. section 6.1). Referred to the theory, this effect makes sense since a higher level of immersion has several beneficial effects on crucial elements of learning. Authors mentioned positive correlations between the level of immersion and a decreased cognitive burden, an increased enjoyment or engagement and better memorization (Agarwal and Karahanna, 2000; Bredl et al., 2012; Dede, 2009; Lin et al., 2002; Liu et al., 2014; Mania and Chalmers, 2001; Ragan et al., 2010, 2012; Witmer and Singer, 1998).

As seen earlier, study #1 (cf. section 6.1) investigated the recall accuracy and the level of immersion. The experiment included two groups that were given different displays for the use of the VMP. Results indicated a superiority of more immersive displays like a HMD (Huttner and Robra-Bissantz, 2017). However, the study did not actually measure the level of immersion but rather compared two different types of displays like a desktop screen and a HMD. Therefore, this study involves a questionnaire to assess the participants' level of immersion. Agarwal and Karahanna (2000) suggested a five-item construct called Focused Immersion (FI) which was originally built for the analysis of immersive web applications. Again, the items were slightly rewritten to fit the context of the VMP. Hence, the last two hypotheses are the following:

H3: The users' level of immersion significantly predicts a positively correlated strict score

H4: The users' level of immersion significantly predicts a positively correlated lenient score

Summarized, this study focuses on the participants ability to recall information and the possibly correlated perceived usefulness as a crucial factor for practical VMP solutions in future research. Also the level of immersion shall be analyzed as a driving factor for the memorization performance. That is why the other TAM constructs are not analyzed in detail. As already mentioned, the hypotheses were evaluated by an experiment with a paired sample.

6.3.2 Experimental Design

This section gives a brief description of the experimental context including the participants, the VMP prototype and technology as well as the procedure. As described above, the memorization performance was operationalized as the recall accuracy by the strict and lenient scores. Therefore, a list of words served as the to-be-remembered items. This list was not composed randomly but consisted of 40 terms. The amount of 40 was suggested by Ross and Lawrence (1968), especially for the evaluation of the MOL. In addition to that, all of the terms were highly concrete. This design aspect was chosen in order to lower the participants (mostly beginner level) effort to visualize the to-be-remembered items. As explained earlier, the successful application of the MOL heavily depends on the ability to create mental images in one's mind. This aspect was also described by Legge et al. (2012), they mentioned that terms of a high concreteness are overall easier to remember than abstract (low concreteness) words. For instance, a term that has a high concreteness would be table, which is easier to visualize than a term like wisdom. Therefore, the list of terms was taken from a study performed by Kanske and Kotz (2010). They used a survey to evaluate approx. 1000 words and their corresponding norms, e.g. the level of concreteness. Howsoever, participants were told to apply the vMOL by the help of the VMP prototype. So, the subjects had to traverse the VMP in a predefined path (due to the static position of the loci) and memorize the loci. A more detailed description of the technology, the prototype, the participants and the procedure will be given in the following sections.

6.3.2.1 Technology

The important role of an immersive display for the application of a VMP was already described. In order to offer the users an immersive experience, at least more immersive than a common computer screen (Ragan et al., 2010), the VMP was built for a head-mounted display (HMD). More precisely, it was implemented as a virtual reality (VR) environment. This design decision is also encouraged by the potential lying in the VR technology for educational purposes, especially at a time in which the necessary hardware becomes more and more affordable for the majority of the people (Martín-Gutiérrez, 2017). In detail, the VMP environment was generated as a smartphone application (developed with Unity 3D). The smartphone was then put into a goggle that integrates the phone as a stereoscopic display. Two lenses in the goggle project the two separated images into the user's eyes (see figure 6.3). Based on this mechanism, the user perceives the environment in three dimensions. So, every participant was given such a HMD plus a wired gaming controller to navigate through the virtual world. In addition to that, every subject was put on a swivel chair to easily look around in the VR (the head movement was tracked and translated by the application). Also, this should avoid possible problems with the subjects' sense of balance while traversing the VMP.

6.3.2.2 Prototype

The prototype did not only consist of the VMP itself, but also offered each participant a mandatory training level. In this manner, the procedure ensured that the users understood how to walk around and how to interact with the loci. After passing the training level, the user was spawned into the VMP and the memorization task began. As shown in Figure 6.3, each locus consists of a combination of text (in this case "Zeitung", engl. newspaper) and a corresponding sketchy image.

The VMP was designed as an apartment (similar to Legge et al. (2012)). The loci were implemented at fixed positions, so the order of the to-be-remembered terms did not vary. The user started the memorization task at the entrance of the apartment. The first locus was placed at the spawn position. However, the

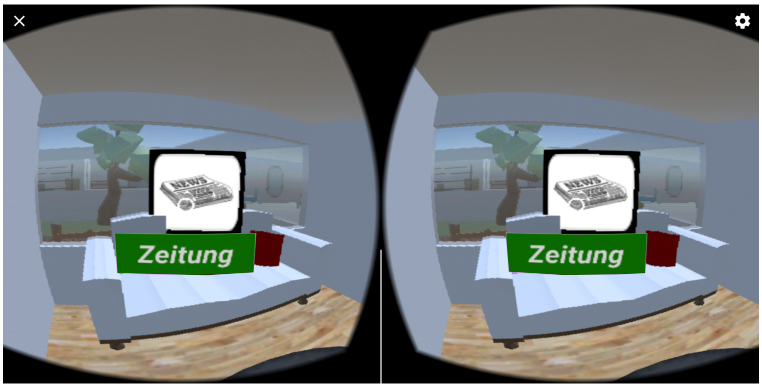


Figure 6.3: Locus in the Image-Text VMP (Study #3)

loci were not visible all the time in order to reduce a bias caused by the time a participant chose to actually look at a specific locus. Therefore, each locus was initially hidden in a floating square with a question mark on it. A fixed dot in the center of the field of view served as a selection cursor. So, the user had to focus the dot on the square and press a controller button to reveal the locus (e.g. term and image). After that, the locus was uncovered for five seconds and then disappeared, so participants only had a limited timespan (also adopted from Legge et al. (ibid.)) to memorize the term. Furthermore, every following locus (square with question mark) appeared right after the antecedent one disappeared. That way, the order in which the terms were presented to each participant was always the same.

6.3.2.3 Participants

Overall, 47 undergraduate students took part in the experiment. Most of them major in technically fields of study. Note that the students were not incentivized in any manner to participate in the study. German was required to be the participants' mother tongue since the list of terms were also in German. Hence, a bias due to misunderstandings was avoided. Another possible biasing factor was the problem of motion sickness (MS). Participants partly suffered from MS due the VR experience. It is an effect that might occur if the user perceives a discrepancy between the visual stimulus and her/his actual head movement Hettinger and Riccio (1992). As a result, the subjects' level of immersion drops and they cannot longer focus on the task Witmer and Singer (1998). Four of the students had to quit the memorization task due to MS. Hence, these four were removed from the dataset leaving a sample of 43 participants (female = 17, male = 26, aged between 18 and 29, mean = 24,00). Later in the long term recall phase, 30 of them took part. All of the participants had only little to none prior experience in the application of the MOL.

6.3.2.4 Procedure

The experiment was conducted over a timespan of roughly six weeks. Each participant performed under the same conditions. Figure 6.9 shows the six phases each student had to master. In phase one, each subject was instructed on how the MOL works and how to apply it. Then, participants were handed the HMD and the gaming controller. The training level started and the subjects had to walk around and activate an example loci to understand and become confident with the handling. After fulfilling this task, they were spawned into the VMP and the memorization phase started. This phase did not have a time limit but on average, participants spend 628,526 seconds in the VMP (std. dev. = 192,177 seconds). After the students finished the memorization task, they were given a website to enter the 40 terms. The design of the website was closely aligned to the one described by Legge et al. (2012). First, a brief description was given on how to enter the terms. Participants were asked to enter one term after another. The page consisted of a white background with only a single input field in the center of the display and a submit button.

	Phase
1	Instructions for the virtual MOL
2	Passing the training level
3	Navigating through the VMP and remembering the loci
4	Recall Phase
5	Questionnaire
6	Invitation to long-term recall phase

Table 6.9: Procedure of the Experiment (Study #3)

In the fifth phase, the students received a questionnaire to collect their demographic information plus the Likert – scaled items of the TAM, FI and motion sickness. The last phase intended to test the subjects' long term memory. So, after one week they were asked via e-mail to repeat the recall phase. By following a hyperlink they were referred to the exact same interface of phase four. Overall 30 students completed this long term recall phase. Note that the students were not informed about the long-term recall task in advance.

6.3.3 Analysis & Results

Before the data was analyzed, the following revision steps were carried out. First, the subjects' input was revised. As explained earlier, the memorization performance was operationalized as the recall accuracy using the strict and lenient scoring method. Hence, these scores represent two different approaches of calculating the amount of words each participant was able to remember. One respected the right order (strict score) the other one did not (lenient score). While reviewing the input in the database, in some cases spelling mistakes were found or participants chose a wrong pluralization. These kind of mistakes were not considered as representative factors for the participants recall accuracy. Therefore, these terms were corrected (e.g. foork or forks were afterwards changed to fork, but only if it did not change the original meaning of the term). The lenient score was simply calculated as the percentage of the correct terms that occurred in the participants input. The strict score was calculated using the levenshtein distance (also edit distance). This algorithm is used to calculate the minimum costs of transforming one sequence (e.g. a string or an array of terms) into an original one (Levenshtein, 1966). The algorithm includes three basic operations: replace, delete and insert. Every time the algorithm has to use one of them, a counter increments the costs of transformation by one. In the end, the minimum costs are returned. For instance, the original sequence is table, spoon, fork, apple, banana while the user's input was spoon, fork, apple, banana, table. In this case, the order is almost perfect except for the term table. The levenshtein distance then deletes table and adds it at the beginning of the sequence. Hence, two operations were performed (deletion and insertion) and the cost of transforming the sequence is two. The strict score was then computed using the following formula:

strict score = 1 − lev(u,o) / max

The function **lev(u,o)** returns the levenshtein costs of the user input sequence **u** and the original sequence **o**. The value **max** represents the maximum amount of operations that might be necessary to transform any given sequence of terms (worst case scenario, in this setting it is the maximum length of the original sequence) into the original one. Hence, regarding the example the strict score would be **1 − 2/5 = 0.6**. This way of computing the strict score ensures an objective measure of the subjects ability to recall the terms in order. Furthermore, an increasing memorization performance results in an increasing strict score that ranges between 0 and 1. Table 6.10 gives an overview to the descriptive statistics of the variables (with N = 43, as mentioned in section 6.3.2.3).

Variable	Mean	Median	Std.Dev.
Strict score (short term)	0.404	0.375	0.267
Strict score (long term*)	0.298 (-26.23%)	0.225 (-40.00%)	0.283
Lenient score (short term)	0.707	0.725	0.186
Lenient score (long term*)	0.606 (-14.29%)	0.625 (-13.79%)	0.256
Focused Immersion	5.502	6.000	1.118
Perceived Usefulness	4.810	5.000	1.395
*N = 30			

Table 6.10: Descriptive Data (Study #3)

As seen in the data, the participants' average recall accuracy dropped within one week by 26% regarding the strict score and 14% regarding the lenient score. So, the ability to recall the terms in order, decreased relatively further than the general recall accuracy. The mean and median of the variables Focused Immersion and Perceived Usefulness lie above the average of 4 and therefore indicate a positive tendency.

6.3.3.1 Internal Validity

In order to determine the correctness of the measures, Cronbach's alpha was calculated. The results show sufficient values above 0.8 and 0.9 (Cronbach, 1951). Note that none of the respecting variable items had to be dropped in order to increase the internal validity: Immersion: 0.831; PEOU: 0.932; PU: 0.943; BIU: 0.984; TAM: 0.928. In the following, the assumed relations between the memorization performance and the user's perceived usefulness, as well as the immersion and the recall accuracy was investigated by performing a correlation analysis.

6.3.3.2 Regression Models

In order to check and model the hypotheses, corresponding linear regressions were calculated if a correlation was found on a significant level ($p<.05$) or at least a trend effect of $p < 0.1$. Note that due to a lack of normally distributed data and the ordinal scaled TAM items, correlations were calculated using Spearman's Rho (Backhaus et al., 2015). Except for the influence from the factor immersion

IV	DV	Std. error	Beta[1]	F-Stat.	Adj. R^2	Cohen's D	Corr.
Strict ST	PU	0.740	0.420	8.797	0.157**	0.4315	0.420**(S)
Lenient ST	PU	1.057	0.426	9.064	0.161**	0.4380	0.392**(S)
FI	Strict ST	0.041	0.271	3.181	0.051^{tr}	0.2318	0.302^{tr}(S)
FI	Lenient ST	0.028	0.310	4.260	0.074*	0.2827	0.307*(S)

Significance: ^{tr} $p<.1$ (trend effect); * $p<.05$; ** $p<.01$; (S) = Spearman's Rho; **1** = Standardized;
Strict ST = Strict Score (short term); Lenient ST = Lenient Score (short term);
PU = Perceived Usefulness; FI = Focused Immersion

Table 6.11: Regression Models (Study #3)

on the strict score, every other assumed model is significant on a level below .05 and shows at least an approx. average effect size (Cohen's D: average > .25, strong > .40)(Cohen, 1992). The corresponding coefficients of determination (r-squared) show a moderate (H1 & H2) and a weak (H3 & H4), but yet notable proximity of the data to the model (substantial: < .26, moderate: < .13, weak < .02)(Cohen, 1988). The recall accuracy moderately explains the users' perceived usefulness while the level of immersion slightly predicts the recall accuracy. Hence, the assumed effects are not really strong, but still, they exist and support the described theory. Furthermore, the data analysis revealed a positive correlation between immersion and PU (Spearman's Rho: 0.505, $p < .01$) as well as immersion and BIU (Spearman's Rho: 0.483, $p < 0.01$). Therefore, in the context of a VMP, the level of immersion might play an important role for the technology acceptance and certainly is an interesting issue for further studies in this domain.

6.3.3.3 Limitations

Since this study involved a controlled laboratory experiment, some limitations need to be mentioned. The participants were exclusively and technically oriented undergraduates in their mid-twenties. Hence, future studies should try to find more diverse participants. Furthermore, the instrument to measure the level of immersion had the lowest, yet sufficient, internal validity compared to the TAM variables. Maybe another, more extensive questionnaire could improve the measurement (e.g. Witmer and Singer (1998)). Another limitation needs to be outlined regarding the last phase of the experiment. Since the invitation to the long term recall task was sent via e-mail, one week later, it could hardly be ensured that participants took part immediately. Although the students were not informed about the long-term recall task, it is also possible, that some of them anticipated this phase and wrote down the terms right after the initial experiment. Furthermore, in order to evaluate the long term memorization performance more elaborately, a control group would certainly be helpful.

6.3.4 Discussion & Conclusion

In order to underline the power of the MOL, the first aspect that will be discussed is the long term recall accuracy. The vast majority of participants in this study (who took part in the long term phase) scored substantially better results than indicated by the forgetting curve (c.f. Ebbinghaus (1885)). The forgetting curve shows the relation between the ability to recall rate in percent over time (ibid.). Ebbinghaus conducted a self-experiment and derived the famous curve, which was validated and confirmed by other authors in this research domain (Murre and Dros,

2015) (see figure 6.4). Note that some participants even scored more than 100% in the long term task. This is possible, as the students short term performance (in this case the lenient score) was the reference for the comparison with the long term performance. So, the achieved lenient score represented 100% regarding the calculation of the forgetting rate. In other words, after one week some students were able to remember more terms than right after the experiment. The results of the

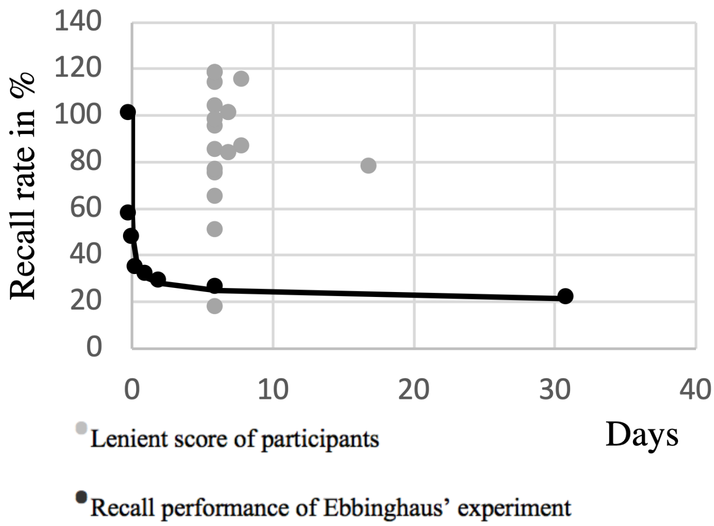


Figure 6.4: Lenient Scoring Results vs. Forgetting Curve (Study #3)

data analysis showed mostly significant regression models for the assumed correlations. Hence, the hypotheses H1, H2 and H4 cannot be rejected at this point. The positive influence of the level of immersion on the strict score is only supported by a trend effect (H3). However, it seems that the users' perceived usefulness, which is an important factor for the technology acceptance, is substantially driven by the memorization performance. Therefore, further research in this promising domain shall be encouraged to strive for a more holistic concept of a VMP. As seen in section 6.3.1, all related work mainly focused on research questions that involved only trivial loci. To this day, there are no studies that investigate a VMP which visualizes more complex learning content or implements further mechanisms to address higher levels of learning (cf. Bloom's Taxonomy, section **??**). Furthermore, the level of immersion has a positive influence on the recall accuracy. This correlation was already suggested, partially analyzed and promoted by Huttner and Robra-Bissantz (2017). However, in order to fully understand important immersion factors for the VMP concept, further research is certainly necessary. Possible research questions might evaluate which kind of immersion leveraging features suit best for this concept (e.g. intense interaction with the loci, the type of display or auditory cues (Dede, 2009; Ragan et al., 2010)).

6.3.5 DSR Cycle #3

The third cycle included a second iteration to investigate the influence of immersive presence on the memorization performance. This time, the latent, independent variable "immersion" was measured using the construct "focused immersion" by Agarwal and Karahanna (2000). The relation between immersion and recall accuracy was illustrated by linear regression models. Furthermore, a more or less obvious, but still crucial correlation of any DSR approach was illustrated. The users' perceived usefulness of the artifact, which is important for a practice oriented approach, is positively influenced by the users' memorization performance. In other words, if the tool actually helps to improve the users' recall accuracy, the more likely she or he actually considers to use a VMP. A further DSR contribution was suggested in this cycle by the calculation of the strict score using the formula based on the levenshtein distance (cf. 6.3.3). The following DSR cycle investigated the last of the three identified design domains for the VMP concept: The users' awareness of the MOL as a requirement to successfully use a VMP.

6.4 Study #4: The Users' Awareness of the Method of Loci

6.4.1 Theoretical Background & Hypotheses

This study aims to contribute to further simplify the application of a VMP by investigating the recall accuracy after a mere exposure to the visuospatial VMP and without conscious awareness of the MOL. By doing so, the results shall also give a hint to answer the research question in section 4. As part of the VMP concept, an introduction to the MOL is either optional or obligatory in the design of the training phase (cf. section 2.3). In the following sections, the experimental and the prototype design will be introduced. The results of the evaluation and discussion of the findings as well as the conclusion will be covered in the later sections. In order to investigate the effectiveness of the MOL without the conscious awareness of the application of this method, an experiment was conducted to investigate the hypotheses in this study. Participants were divided into three groups. Group 1 was defined as one group with the conscious awareness of the MOL (cMOL = conscious MOL), group 2 as the one without such awareness (uMOL = unconscious MOL) and group 3 as a control group using the traditional MOL (CON = control). This control group was also asked to use the MOL, since the experimental design should allow to compare the traditional versus the virtual MOL. Moreover, several studies already reported on the superiority of the MOL over traditional, non-mnemonic learning strategies. Obviously, to examine a mere exposure to the visuospatial VMP would also enhance learning performance, participants in group 2 (uMOL) should not be aware that they were learning the list of words that were presented. Otherwise, it would be difficult to control whether some participants, who already had experience with this method, would consciously or subconsciously apply the MOL. Moreover, in order to control the fact that different tasks may result noticeable difference in recall accuracy, the participants of all three groups were instructed with the same fake task instead of the real memorization task. Later, it will be discussed in detail whether the fake task could lead to a general decrease in recall accuracy. However, as long as all the participants were given the same task, this decrease should occur equally in all three groups. Hence, it should not interfere with the aim of this study. Bellezza and Reddy (1978) conducted an experiment to investigate if the MOL works like the natural memory process. They compared the recall accuracy of participants using familiar loci provided by themselves and unfamiliar loci provide by the experiment designer with a control group. None of the participants was informed about the recall task in the first place. Instead, they were asked to rate the concreteness of a list words after the session, in which they should firstly imagine the word and then place it in the loci (ibid.). In this study, a similar methodology is adopted and it focuses on finding out the influence of conscious awareness of the existence of this method on the participants' memorization performance. Hence, none of the participants were informed about the real task. Instead, participants were told that the purpose of the experiment was to test their visual imagery and imagination. Similarly, all the participants in this study were informed that the experiment aims to test personal visual imagination. Therefore, they were given a word and an image. The fake task then was that they should rate the similarity of the images presented to them with their own imagined pictures of these words. Participants were also told, they should interact with the words and images before they rate the similarity. Subjects in Group 1 (cMOL) and 2 (uMOL) should explore the VMP and interact with the words and images firstly. The only difference is that participants in Group 1 were given a brief introduction of the MOL and what a VMP is. But they were told that the experiment is not about memorization but rather the rating task to improve design features in a VMP. Participants in group 3 (CON) were also introduced with the MOL because for interaction with these words and images, they should associate the objects with loci in their own memory palace. In the post-experiment questionnaire, all participants were asked if they had already anticipated the real task during the experiment (dichotomously: yes or no) since this may influence the variance of the participants' recall accuracy. To measure the memorization performance, two approaches were used. They were introduced by Legge et al. (2012): the strict score and the lenient score. The strict score reflects the percentage of the correct words in the correct position. A detailed description of how it was calculated will be given in section 6.4.3. The lenient score measures the overall proportion of words that could be recalled, regardless the correct position. The effectiveness of the MOL, without conscious awareness of its existence, yet remains a relatively unexplored area of research. Therefore, no superior performance of any group was assumed. Hence, the derived hypotheses are as follows:

H1: There will be no statistically significant difference between the conscious MOL group and the unconscious MOL group on the lenient score.

H2: There will be no statistically significant difference between the conscious MOL group and the unconscious MOL group on the strict score.

6.4.2 Experimental Design

This section gives a description about the experimental settings, i.e. the participants and stimuli, prototype and technology, as well as the experimental procedure.

6.4.2.1 Participants

A total of 62 participants, aged 21-34 (mean = 25.51, 37 males, 25 females) participated for no financial incentives. 58 of them are university students and 4 of them have already graduated from university. Participants signed-up for the experiment via an online system and were randomly assigned to one of the three groups. Note, participants who are non-native German speakers are all students in a German university attending lessons and exams which are conducted in German. Also, they were equally distributed in three groups. Hence, this factor is not considered as an independent factor having an impact on the result. Two groups conducted the session in a VMP (Group 1: cMOL = conscious MOL, Group 2: uMOL = unconscious MOL) and the third group conducted a traditional mental MOL session serving as a control group (Group 3: CON = control). Three participants (1 male, 2 females) reported severe motion sickness and withdrew from the experiment. Two participants' recall results were not recorded in the database. Hence, a total of 57 participants provided data for this study (Group 1 cMOL: 23, Group 2 uMOL: 22, Group 3 CON: 12). A control condition without any MOL application was not considered in this study because of two main reasons. First, the statistical power would be even lower due a limited sample size. Second, the benefit of the MOL was shown in many studies as mentioned in earlier sections (Bellezza and Reddy, 1978; Legge et al., 2012; Maguire et al., 2003; Qureshi et al., 2014). The effect of conscious awareness of the MOL on recall accuracy would only be meaningful on the premise of the benefit of this mnemonic. Therefore, this study mainly focuses on the effect of the conscious awareness of the MOL (comparison between cMOL and uMOL).

6.4.2.2 Stimuli

Bellezza (1981) suggested that a list with less than ten words should be avoided for a MOL investigation, because the effectiveness of the MOL would not be noticeable in that case. Furthermore,Malaga (2000) pointed out that if a picture is named to a subject, certain images may appear in his/her visual mind while reading a particular word. According to the dual coding theory of Paivio and Lambert (1981), a simultaneous presentation of pictorial and lexical stimuli results in an improvement of the retention performance. Also the studies from Fleming (1979), Shepard (1967) and Standing (1973) supported the statement that a superior memorization performance can be achieved with the help of a combination of text and images over either only texts or images being presented. Hence, a list of 40 words was used as stimuli as Ross and Lawrence (1968) suggested and applied in their study. Along with the words, 40 images were presented simultaneously. The concreteness of nouns, i.e. the difficulty level for people to form mental images of the word, could influence the recall accuracy according to Bellezza and Reddy (1978). Also Legge et al. (2012) pointed out in their study that words with high concreteness are easier to remember in general than those with low concreteness. To lessen the mental effort for participants, the terms were taken from the list "Leipzig Affective Norms for German (LANG)" (Kanske and Kotz, 2010), in which a list of 1,000 German nouns were rated for emotional valence, arousal, and concreteness. Nouns with top 40 concreteness combined with images were chosen as stimuli for this experiment.

6.4.2.3 Prototype & Technology

Jund et al. (2016) suggested that a higher level of immersion should positively influence the vir-tual MOL experience. Legge et al. (2012) also stated that the use of VR has a positive influence on the users' intention and ability to apply MOL. Since the aim of this study is to further reduce demanded mental effort for the MOL when entering a VMP in an educational context, the VMP was developed for a head-mounted display (HMD). A HMD generates a higher immersion than a mere application of a regular screen. Participants in group 1 (conscious MOL) and 2 (unconscious MOL) conducted this experiment in a virtual reality environment wearing a HMD with a smartphone as the display. The smartphone screen generates a stereoscopic camera perspective focused by two lenses in the actual HMD. Participants can navigate themselves in the virtual environment by using a Play Station gaming controller. In addition to that, participants conducted this session in a seated position with a rotary chair. This way, participants were able to look around easily and navigate with little effort. The VMP was designed as a virtual apartment and the loci were covered as a white box with a black question mark on it. Participants were spawned at the entrance of the apartment where the first locus was placed. The loci were not visible or accessible all at once so participants had to uncover them one after another. This way, the VMP design ensured that participants had to follow a predefined walking path in an VMP to find all the loci. The user had to focus on the square and press a controller button to activate the locus (term and image). Each item was presented for five seconds and then disappeared. In order to reveal the next item, the participant had to find it nearby. The objects in the VMP were located quite close to each other and no participant reported difficulties to find them. The time frame of 5000 ms (or 5 seconds) was adopted from the study conducted by Legge et al. (ibid.). Figure 6.5 shows an uncovered locus in the VMP ("Brief" means letter) in a stereoscopic camera perspective. Due to this procedure, the interstimulus interval was determined by

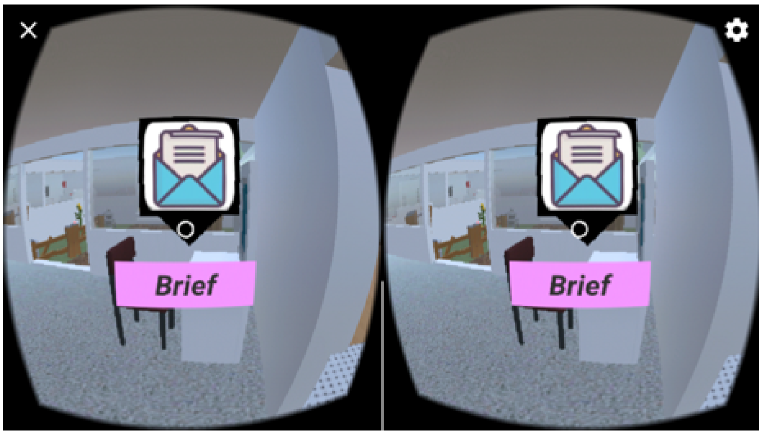


Figure 6.5: Locus in the VMP (Study #4)

the movement behaviour of each participant. For the control group conducting a traditional mental MOL, words and images were presented with a Macbook Pro with a 13.3-inch screen. Same as for the other groups, each stimulus was presented for five seconds and disappeared afterwards. By pressing a button on the laptop, the next stimulus appeared on the screen, so the conditions resemble the ones in the experimental groups.

6.4.2.4 Procedure

Before the experiment started, all the participants were briefed as follows, which was modified from the experiment conducted by Bellezza and Reddy (1978). "This experiment aims to test personal visual imagination. In this session, you will be presented with 40 words with pictures. After the session, you will be asked to rate the similarity of these pictures with your own mental imagined pictures of these words. At the end, we will ask you to fill a questionnaire to give us a feedback of the general experience." In addition to the Information above, participants in different groups were given additional information accordingly as mentioned in the previous section. Participants in Group 1 (cMOL) and 2 (uMOL) were asked to explore the VMP and interact with all the words and images. The only difference is that participants in Group 1 were given a brief introduction to the MOL (see Appendix)and were told that the VMP they were going to explore was designed according to the MOL. Participants in group 3 (CON) were also introduced with this method because they had to imagine their own memory palace and associate the objects with the loci. The words and images presented to group 3 were exactly the same as those that were presented to group 1 and 2. Then, a training session was provided for them to get familiar with the navigation technique so that the interaction should not interfere with the real memorization task. After the participants were confident with the navigation and the interaction, the experiment started. Participants conducted their sessions according to their group. Once it was completed, the retention procedure began immediately. At this point subjects were informed about the real task to recall the 40 words in order. Table 6.12 illustrates the different phases of the experiment.

	uMOL	cMOL	CON
1	Fake Task	Explanation MOL & fake task	Explanation MOL & fake task
2	Passing the training level	Passing the training level	Presentation: words and images
3	Memorization in the VMP	Memorization in the VMP	
4	Recall phase	Recall phase	Recall phase
5	Questionnaire	Questionnaire	Questionnaire

Table 6.12: Procedure of the Experiment (Study #4)

The recall task was conducted on a web interface which was developed to save the subjects' input in a database. This blank page with a single text field and two buttons (one for input confirmation and one for skip) was also developed according to the one Legge et al. (2012) used for their study. The time limitation of the recall task was set to 10 minutes. When the recall task was completed, all of the subjects were asked to fill a questionnaire about their gender, age, educational level as well as other feedback of this session. Also, they were asked about whether they had pointed out the true intention of this experiment.

6.4.3 Results

As mentioned earlier, the memorization performance was operationalised as the lenient and strict scores. Calculating the lenient score is quite simple as it is only the amount of correct words that could be recalled. The strict score also includes the position of the recalled term (e.g. the correct order in which the terms were presented). As suggested by Huttner et al. (2019b), the calculation was performed by the help of the levenshtein distance (or edit distance). This algorithm calculates the minimum costs of transforming a given sequence (in this case the sequence of the loci or terms) into an original one (Levenshtein, 1966). The costs increase by one for every operation necessary for the transformation (replace, insert or delete). The strict score was finally built with the following formula: strict score = 1 − (lev(i,j) / max). The function lev(i,j) calculates the minimal costs to transform i into j. The denominator max represents the maximum costs that are possible for a defined sequence j. Due to this calculation of the strict score, the measurement is performed objectively and therefore suits the requirements for a statistical analysis. Before the data was analysed, the participants' input was corrected from spelling mistakes and pluralization (all words were presented in a singular form in the experiment). The statistical analysis was conducted using the open source software R (version 1.1.463). Table 6.13 gives an overview to the relevant descriptive statistics. While the experimental groups appear to be quite similar regarding the recall accuracy, the control group achieved higher scores. Moreover, the percentage of subjects who anticipated the original memorization task is higher than expected. These issues will be covered in the upcoming analysis.

	uMOL		cMOL		CON	
	Mean	Median	Mean	Median	Mean	Median
Lenient Score	.4565	.4250	.4522	.4750	.5692	.6500
Strict Score	.1054	.0500	.1076	.1000	.3308	.2000
Motion Sickness	3.304	3.500	3.130	3.500	NA	NA
Anticipation	17 of 23 (74%)		14 of 23 (61%)		12 of 13 (92%)	

Table 6.13: Descriptive Statistics (Study #4)

The boxplots in figure 6.6 illustrate the difference between the control group and the experimental groups more clearly. Especially the strict scores differ substantially. The control group is characterized by a wider range within the middle 50% of participants and also achieved a higher maximum score. The strict scores in the experimental groups are closer distributed and indicate a more homogenous scoring performance. A similar phenomenon can be seen in the lenient scoring between the groups, although it is not as notable as in the strict scoring perspective.

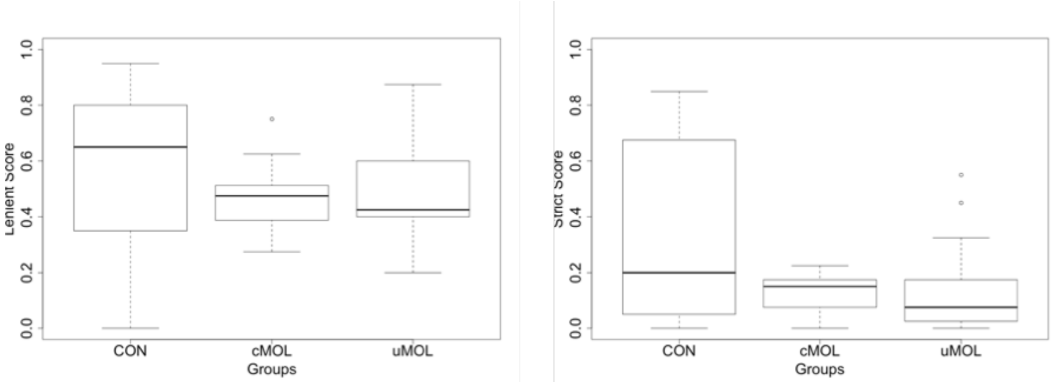


Figure 6.6: Comparison of the Recall Accuracy (Study #4)

6.4.3.1 Motion Sickness

All the participants of the cMOL and the uMOL group were asked to rate the motion sickness they perceived during this session on a five point likert-scale afterwards. A higher score indicated a higher perception of motion sickness. Since motion sickness is reportedly biasing the participants' performance in virtual reality settings, simple linear regression models were calculated to examine if this effect also applies in this study. Hence, models were built with motion sickness as the independent and the strict and lenient scores as the dependent variables. A significant regression equation (on a level of $p<.05$) was found in the uMOL group (see table 6.14).

Furthermore, the influence of motion sickness on the lenient score in the uMOL group also shows a trend effect ($p<.1$, compare Legge et al. (2012)). The negative coefficients (beta 1) support the theory that a higher level motion sickness decreases the subjects' task performance. To improve the reliability of the analysis, all the participants with a motion sickness level above three were excluded in both of the experimental groups (leaving 15 participants in each experimental group). Thus, the effect of motion sickness could be excluded to a sufficient degree

	uMOL		cMOL	
	Strict Score	Lenient Score	Strict Score	Lenient Score
F-Statistic	F(1,21) = 5.381	F(1,21) = 3.119	F(1,21) = 1.795	F(1,21) = 1.380
p-Value	.0305**	.0919*	.1946	.2533
Adj. R^2	.1661	.0879	.0349	.0170
Beta 0	.2692	.6271	.1598	.5158
Beta 1	-.0496	-.0516	-.0167	-.0203

Levels of significance: p<.05**; p<.1* (trend effect)

Table 6.14: Influence of Motion Sickness on Recall Accuracy (Study #4)

(new p-values in the uMOL condition: $p_{strict} = .4496$, $p_{lenient} = .281$). Note that the removal of the participants did not alter the significance in the cMOL group ($p_{strict} = .8967$, $p_{lenient} = .8835$).

6.4.3.2 Analysis of the Factor Anticipation

According to the descriptive statistics (see table 6.13), the vast majority of the participants anticipated the real task of recalling the presented items (cMOL: 61%, uMOL: 73%, CON: 92%). There-fore, it is reasonable to assume that the factor of anticipation of the original task may bias the possible effect of the treatment on the recall accuracy. In order to investigate this problem, two ANCOVAs were conducted to reveal possible effects and control the factor of anticipation in the analysis (with the strict and lenient scores as dependent variables). Before conducting the ANCOVAs, certain prerequisites regarding the data should be fulfilled. The recall accuracy (strict and lenient scores) was tested for their type of distribution using the Shapiro-Wilk test and Q-Q plots. All of the strict and lenient scores in the respecting groups are normally distributed except for one (cMOL – Strict score: p = .2194; cMOL – Lenient score: p = .4491; uMOL – Strict score: p = .0035; uMOL – Lenient score: p = .2188). Moreover, the Levene's test indicated equal variance of the strict and lenient scores between the two experimental groups (variance of cMOL and uMOL – strict score: F(8,6) = 2.2147, p = .1742; lenient score: F(4,10) = 0.3752, p = .9049). The analysis of covariance of the lenient scores between the experimental groups while control-ling for the factor anticipation shows a significant influence of anticipation on the treatment ($F(3,26) = 3.000$, $p = .04873$). The strict score is not affected by the factor anticipation ($F(3,26) = 1.047$, $p = .3884$).

6.4.3.3 Anticipation only Analysis

The previous analysis showed a significant covarying effect of the factor anticipation on the treatments in both experimental groups. Hence, eliminating the participants who anticipated the original memorization task would be next logical consequence in order to investigate the hypothesized effects. Unfortunately, this would result in an overall insufficient amount of participants for reliable quantitative methods. Therefore, in the following analysis only those participants are removed who anticipated the original intention. This way, the study's outcome will slightly be biased by the factor of anticipation, but as shown above, the majority of the participants foresaw their task and the bias was only present on a significant level in one group only. After eliminating the data of the non-anticipating subjects, the cMOL group has a remaining data set of eight and the uMOL group has a remaining data set of thirteen subjects. In order the investigate H1 and H2, the cMOL and the uMOL group were again tested on their normal distribution. Shapiro-Wilk tests indicate that both, the strict and the lenient scores are probably normally distributed in the uMOL condition, while both recall scores in the cMOL condition are not (cMOL – Strict score: $p = .5434$; cMOL – Lenient score: $p = .1895$; uMOL – Strict score: $p = .0099$; uMOL – Lenient score: $p = .0155$). Based on this results, a Wilcoxon Rank Sum test fits the requirements for a comparison of the means of the experimental groups (see table 6.15). The results of the

	Lenient Score	Strict Score
W	57.5	40
$W_{critical}$	53	53
p-Value	.7146	.4025

Table 6.15: Results of the Wilcoxon Rank Sum Tests (Study #4)

comparison of the lenient scores show that the null hypothesis cannot be rejected at this point. The level of significance is above .05 and .1. At the same time, the value of $W_{critical}$ (53) is exceeded ($W = 57.5$). Similarly, the results of the strict score analysis does not support a significant difference between the cMOL and the uMOL group.

6.4.4 Discussion

6.4.4.1 Recall Accuracy

The analysis shows that the recall accuracy was not significantly different between the experimental groups. This result motivates a further simplification of the VMP concept. In a use case where users do not have to be informed about the exact strategy or how it works, developers and practitioners may focus on other design aspects. Moreover, the results support the theory of the underlying mechanism of the MOL (Maguire et al., 2003), which seems to work independently from the exact knowledge about it. Confusion may arise when comparing the cMOL and uMOL group with the control group. The recall accuracy of the control group is better compared to the ones of the other two groups. First of all, this may be explained by the vast majority of participants who anticipated the real task as mentioned in section 6.4.3.2. Hence, they probably memorized the words more consciously which resulted as an overall better performance. Secondly, it was already mentioned that the limitation of the experimental design could have led to an inevitable, better performance of the control group. Participants were not informed of the memorization task, which may had lead to concerns that this study has not much to do with the MOL mnemonic itself. Another reason could be found in the navigation method since Ragan et al. (2012) found out that complex control mechanisms might decrease memory performance in virtual reality settings. However, the benefit of this mnemonic is not the focus of this study. A further explanation of the better performance of the control group would be that the test environment was more similar to the learning environment in the control condition than in the virtual conditions. Craik and Tulving (1975) tested the retention performance of people under vs. above water, where words that had been learned under water were better recalled under water and vice-versa.

According to their study, it is possible that the test environment restricted the retention performance of the virtual groups. In real life learning scenarios, it is not practical to always have support from the VMP when applying the obtained knowledge. Hence, the test results comparing the virtual groups with the control condition could reflect real life learning situations and performance. This may be explained by the percentage of prediction of the real task. Almost all participants in the control group predicted the real intention of the experiment, which may cause them to memorize the words consciously. However, the most important comparison for this study was found between the groups cMOL and uMOL. A statistically significant difference of the memory performances could not be found. Therefore, it can still be concluded that users can benefit from such learning scenarios even without the preknowledge of the MOL. As for the role of intention to memorize, which as mentioned was decreased for the cMOL and uMOL group, will be discussed in the following section.

6.4.4.2 The Role of Intention to Memorize

The cMOL and the uMOL group conducted this experiment session with a HMD in a VMP, whereas the control group conducted a traditional mental MOL session. According to the studies stating the improvement of task performance with high immersive environments (Agarwal and Karahanna, 2000; Lin et al., 2002; Mania and Chalmers, 2001; Ragan et al., 2010; Sowndararajan et al., 2008; Witmer and Singer, 1998), subjects of the VMP group (cMOL and uMOL) should have scored more than the control group. However, there is a clear disadvantage of these two groups, both in the strict score and the lenient score. This might be explained by the factor that almost all participants in the control group revealed the true intention of this experiment and tried to remember these word instead of letting the learning process occur incidentally. It may imply the fact that the intention to memorize does have a positive influence on the memory performance. By considering this factor, a comparison with the non-anticipation condition only was conducted. Regardless of the application scenario of the MOL, in classroom settings or in self-learning cases, the intention to memorize objects or to learn would probably occur anyways. Overall, this study indicates that it would not be necessary to inform the users of the MOL before they use a learning application designed with the concept of the MOL or before they enter a VMP. Without conscious awareness of the using of this method or even of the existence of method, a mere exposure to visuospatial VMP would achieve probably the same memory performance.

6.4.4.3 Limitation & Future Research

One of the main goals in this paper was to determine whether it is necessary to inform users about the MOL before they enter a VMP. Two main groups of subjects were compared by giving them the same fake task to ensure that subjects in the group uMOL would not be conscious aware of the existence or the application of this method in the VMP. However, more than half of the subjects had anticipated the real intention of this experiment. Hence, it is important for future studies to refine the experimental design especially in the way how subjects should be briefed before the experiment. Thus, participants would be devoted to conduct another task and let the learning occur incidentally. In addition, studies could also be conducted to further investigate the role of intention to memorize when exploring a VMP. For instance, studies can be done to investigate the memory performance when learners receive the learning materials (e.g. botanical terminology) in classroom settings in a VMP without the intention to memorize. It would also be interesting to investigate the long term memory performance after a mere exposure to a visual spatial VMP using the MOL. Huttner et al. (2019a) presented a data set that supported this superiority of the VMP induced long-term memorization performance. Furthermore, comparing recall accuracy over time using a traditional MOL with an unconscious exposure to MOL may provide valuable evidence for researchers to further investigate the applicability of MOL. Results of such studies would not only provide the possibility to simplify the application of the MOL, it will also indicate whether it is practical and meaningful to use VMPs in classroom set-tings for learners aging from children to adult. Another recommendation for future studies regarding VMPs is to include a control group that does not use the MOL to increase the probability of correctly judging whether the MOL was used in the experimental groups. Also, the measurement of motion sickness can be refined by a validated construct (e.g. the Kennedy-Lane Simulator Sickness Questionnaire).

6.4.5 Conclusion

The study expands the knowledge base of the VMP concept. It was demonstrated that even without conscious awareness of the application or even the existence of the MOL the memory performance is not attenuated. Additionally, results imply that the MOL is not particularly useful for remembering objects in order as Legge et al. (2012) also demonstrated in their study, which is contrary to previous research (e.g., Roediger (1980)). The results of this study may provide valuable evidence for applying a VMP tool with the MOL for educational purpose in a more simple way. Nowadays, students are reluctant to use mnemonics because of the mental effort needed before they actually start to use them (Putnam, 2015). This study shows the possibility of applying the MOL even without telling users about this method. For instance, classroom settings with children, where gamification and the MOL may help to memorize vocabulary and learning language (Rawendy et al., 2017), directly applying MOL in a VMP could ease the mental burden for younger learners and motivate them. Similar for classroom settings for higher education, the result of this study may inspire tutors and professors to freely apply the MOL in a VMP to help university students retain new concepts or memorize large amount of terminologies. As mentioned in previous sections, potential classroom settings would be economic and finance, physiology, medical science, or biology (Bloom and Lamkin, 2006; Qureshi et al., 2014; Shaughnessy and White, 2012).

6.4.6 DSR Cycle #4

The last cycle aimed to show whether the awareness of the MOL is important to successfully apply it by the help of a VMP. While the fake task did not work as intended, since participants anticipated the memorization task, the analysis still shows that the knowledge of the MOL is likely not necessary to successfully use a VMP and facilitate the memorization process. Contradictions were found in terms of statistically significant differences between the recall accuracy of the VMP groups and the control group. Possible reasons for that were discussed and should be regarded in future VMP studies and further investigations of this particular research problem.

Being the last DSR cycle to answer the research question, the next section will summarize the results, give a descriptive overview of the collected data and presents the design principles according to (Gregor et al., 2020) as suggested in section 5.3.1.

7 Results

Altogether, four DSR cycles were conducted to investigate three domains of VMP related design issues. In three years, 229 subjects (91 females, 138 males, avg. age = 24.26) took part in these four laboratory experiments. The authors' contributions were read and cited on an international scale (cf. Appendix B 8.2). In the following, the three design domains are discussed concerning the research question (cf. section 4). Each of them will conclude with a design principle according to Gregor et al. (ibid.) and as described in section 5.3.1.

Choice of Display Technology

This first design-related issue of VMPs was addressed by measuring the influence of the factor immersion on the users' memorization performance. DSR cycle #1 and #3 investigated the problem. The first one only found a statistically significant difference between the MOL groups in terms of their compliance rates. Here, a circumscription was identified due to the unexpected, equal memorization performances. Therefore, cycle #3 again included an experimental setting. This time, the experiment did not compare two groups of participants, each using different display technology types. It was rather one group with all subjects following the same protocol in a VR HMD. Here, the five items questionnaire of Agarwal and Karahanna (2000) was used as a measuring instrument for the participants' level of immersion. Since the users' level of immersion depends not only on the type of display but also on subjective tendencies (Bangay and Preston, 1998; Witmer and Singer, 1998), it was expected and later confirmed, that the immersive presence of the participants did not only vary but also positively influenced their memorization performance. This observation was also confirmed by Vindenes et al. (2018) and Krokos et al. (2019) in similar studies. Therefore, it is suggested to use immersive display technologies for the design of a VMP concept. Design principle #1 summarizes the key characteristics.

Design principle #1: Immersive Display Technology

Aim, Implementer, and Users: For software developers and researchers (implementers) to design an effective VMP (aim) for the learners (users)...

Context:...who want to learn declarative knowledge

Mechanism:...ensure to choose a display technology as immersive as possible in the given context

Rationale:...because the more immersive the experience is, the more cognitive processes support the memorization of the learning content (cf. sections 4, 6.1.1, and 6.3.1)

Furthermore, derived from these findings and as mentioned in the studies, there are more ways to increase the users' immersive experience apart from the type of display, such as creating the interaction and the world as realistic as possible (Dede, 2009).

Degree of Visualization

The second DSR cycle investigated whether visualized loci are better suited to help the users' memorization process than imaginary (only textual representation) ones. It turned out that the visualized ones seem to support this process more. The reason behind it is assumed to be the dual coding theory (Paivio and Clark, 1991; Paivio and Lambert, 1981). It states that due to two independent, neuronal mechanisms that process visual and verbal information, the association and therefore memorization process of the subject is improved. Hence, the second design principle is formulated as follows.

Design principle #2: Visualization of the Loci

Aim, Implementer, and Users: For software developers and researchers (implementers) to design an effective VMP (aim) for the learners (users)...

Context:...who want to learn declarative knowledge

Mechanism:...ensure to design the loci as a visible part of the VMP

Rationale:...because due to the dual coding theory, the memorization process of the loci is facilitated by the presentation of text and imagery which are neurologically processed at the same time and therefore strengthen the association between locus and learning content (cf. section 4 and 6.2.1)

Users' Awareness of the MOL

The last DSR cycle aimed to discover a possible difference between a VMP protocol that involves an explanation of how the MOL works compared to a setting where the users are not aware of this method. In order to do this and to avoid a possible, biasing effect of subjects anticipating the memorization task, the participants were given a fake task that also fits the experimental design. However, unfortunately, most students anticipated the real intention of the experiment. Nevertheless, the statistical analysis could show that the fact that users are aware of the MOL is most likely not crucial for the effectiveness of its application with the help of a VMP. Therefore, the last design principle is defined as follows.

Design principle #3: Explaining is optional

Aim, Implementer, and Users: For software developers and researchers (implementers) to design an effective VMP (aim) for the learners (users)...

Context:...who want to learn declarative knowledge

Mechanism:...you can leave out an explanation of what the MOL is

Rationale:...because knowing about it does not improve the memorization performance gained in a VMP (cf. section 6.4.4)

Answer to the Research Question

The results imply that the memorization performance of the user of a VMP is most likely and, amongst others, significantly determined by its design parameters. However, the design principles #2 and #3 are based on only one study. Hence, further studies are recommended to validate these findings, not regarding the research question, but rather to deeper understand the phenomena and the degree to which the VMP should be visualized. Nevertheless, despite the younger maturity of the last two design principles, it is highly probable that the question of whether the design of a VMP influences the user's memorization performance can be affirmed. The theory and the experimental results support a significant impact of VMP design decisions on the users' memorization performance.

8 Discussion

In the beginning, it was argued, that the concept of a VMP is of promising potential for present and especially future educational settings and contexts. After the theoretical framework was described, an extensive literature review was conducted. This review resulted in a document corpus of 30 relevant scientific publications. The analysis showed that the interdisciplinary character of this specific research topic and how diverse and yet promising all the different research approaches of the community are. One major conspicuousness of the work until 2016 lies in the highly differing implementations of the VMPs, more precisely, their design features. Hence, driven by this finding, the research question was if the design of a VMP plays an important role, especially in terms of the users' memorization performance. Due to the complexity of possible design solutions, three representing domains of the design of a VMP were derived from earlier studies. The succeeding description and discussion of epistemological questions and answers lead to the choice of the multi-paradigmatic research perspective: the design science research methodology. It was argued that, especially due to the design-related questions, the pluralism of legitimate research methods, and the iterative nature of creating knowledge, the DSR cycles and the corresponding framework of Vaishnavi and Kuechler (2015) fit for the identified research question.

Subsequently, four DSR cycles were planned, conducted, and reflected on to analyze the three design domains of the research question. As shown in the last section, the results indicated that the design of a VMP does play a significant role in memorizing the learning content. Summarized in the design principles, these findings are thought to support future work in this field, especially for design-oriented research and educational projects.

8.1 Implications & Future Research

The three design principles that resulted from this work are moreover a suggestion, just like the whole DSR approach itself, to encourage future research and colleagues, also from other disciplines, to adopt this methodology in order to unify the research stream. However, there are a plethora of questions and problems to investigate in the VMP research domain. For instance, as described in the beginning, this thesis did only focus on design principles, ignoring the actual design process. Here, there is great potential to contribute valuable VMP design knowledge: How to implement a VMP for a particular educational setting? For instance, how could the design process for a VMP look like that supports a certain lecture? It could be done cooperatively with students attending this particular lecture. A combination of qualitative and quantitative methods would be useful not only to address causalities but also to go deeper into selected design-related questions: How to transform the learning content into particular loci? Is it possible to develop a set of validated rules that guide the designer from any abstract subject towards a visualized locus? These questions are crucial for a mature VMP concept and require a certain amount of creativity in the design process. Future VMP concepts might even include the part where the user himself designs the environment. Modern software-based creativity support systems are shown to be an effective aid for creativity (Redlich et al., 2017) and could be implemented in a VMP editing software to facilitate the design process. These and other relevant issues need to be addressed in the future. Therefore, some younger findings and gaps of the literature review in section 3 (after 2016) shall be highlighted here, additionally to the author's work.

Present Research Gaps

Caplan et al. (2019) conducted an extensive study involving 173 participants. They compared three highly distinctive VMP architectures against each other and concluded that the users' memorization performance does not depend on the mental process of navigating through the memory palace. It would be rather important to build unique loci that ensure the content to be transferred to the LTM. Here, the results indicate that the loci's design is more important than the palace's design, at least when the aim is to optimize the users' memorization performance. O'Grady and Yildirim (2019) also implemented a VMP and concluded how the learners' subjectively perceived effectiveness of the tool pushes their motivation. Therefore, the authors describe the fit of the VMP concept, especially for beginners concerning the MOL. According to the experience gathered in the DSR cycles (sections 6.1 to 6.4), most participants can be accounted for as such. Mann et al. (2017), as well as Yamada et al. (2017) raised questions about how a VMP might benefit from collaborative functions, like a multi-user concept. It could be of interest how, for instance, a collaborative way of creating and placing the loci may improve the VMPs' effectiveness. In this context, future VMPs might also profit from collaborative features since they boost the user's intention to use a virtual environment (Fetscherin and Lattemann, 2008). Hagström and Winman (2018) emphasized the importance of distinctive loci designs to leverage the ease of memorizing them. Vindenes et al. (2018), Peeters and Segundo-Ortin (2019) and Krokos et al. (2019) pointed out how the user of a VMP needs to be able to self-select and place the loci to associate the learning content better with a certain spot. In summary, Peeters and Segundo-Ortin (2019) explained a plausible theory about why design parameters like the first-person view, self-determined navigation, self-selection, and placing of the loci are important for the VMP concept. According to their work, these design features to aid the memorization process, since the users' experience in the VMP activates motor plans. Referring to Shapiro (2019), the authors explain this as cognitive processes which strengthen the memorization due to "active participation of the body" (Peeters and Segundo-Ortin, 2019, p.18). This conclusion aligns with the DSR cycles #1 and #3, which promote an immersive experience of the VMP: the feeling of "being there" could be fostered when the virtual world can be interacted with, involving the motor plan leveraged memorization process described by the authors. Lately, Schöne et al. (2019) described how VR helps to manifest the virtual experience in the episodic memory of the user, which in turn, boosts the memorization performance. This aligns with the explanation given in section 2.2. In summary, more and more related research suggests and evaluates the use of immersive displays like VR technology for the use of interactive learning environments such as a VMP. Another issue highlighted in two publications is about the users' spatial ability and its role in the effectiveness of a VMP. While Huttner and Robbert (2018) described this gap as a possible, relevant factor for the design decisions of a VMP, Vindenes et al. (2018) reported having found a statistically significant correlation between spatial ability and the users' memorization performance. In contrast, Caplan et al. (2019) found the factor of imagined spatial navigation to be not as relevant for the recall performance as expected. Hence, further investigations in this direction should be of use for VMP implementations to come.

Virtual Memory Palaces & Higher-Order Learning

At the beginning in section 2.1, it was explained how the overall, general learning process is complex and multi-leveled (cf. Bloom's Taxonomy (Bloom et al., 1956)). As shown, the traditional MOL and also the current approaches to VMPs are primarily built to help the learner to memorize a certain amount of declarative information. However, here it is argued that a VMP could also be augmented to aid the user beyond the first phase of Bloom's Taxonomy (see fig. 8.1). The MOL concept could be enriched with features that assist the user in the learning process, so that they are guided and supported in this environment until specific capabilities are developed. As a possible outcome, the current concept of a virtual memory palace then evolves to a holistic approach of a virtual capability palace (VCP). It would not only help to memorize facts, but rather serve as a virtual environment that offers teaching functions. However, the maturity of a VMP concept grows from a digital alternative of the traditional memory palace towards a memory palace based, holistic, e-learning environment. Note that, while designing and evaluating the implementation of mechanisms or design features that might help to achieve this goal, possible interference with the underlying MOL should be considered and analyzed.

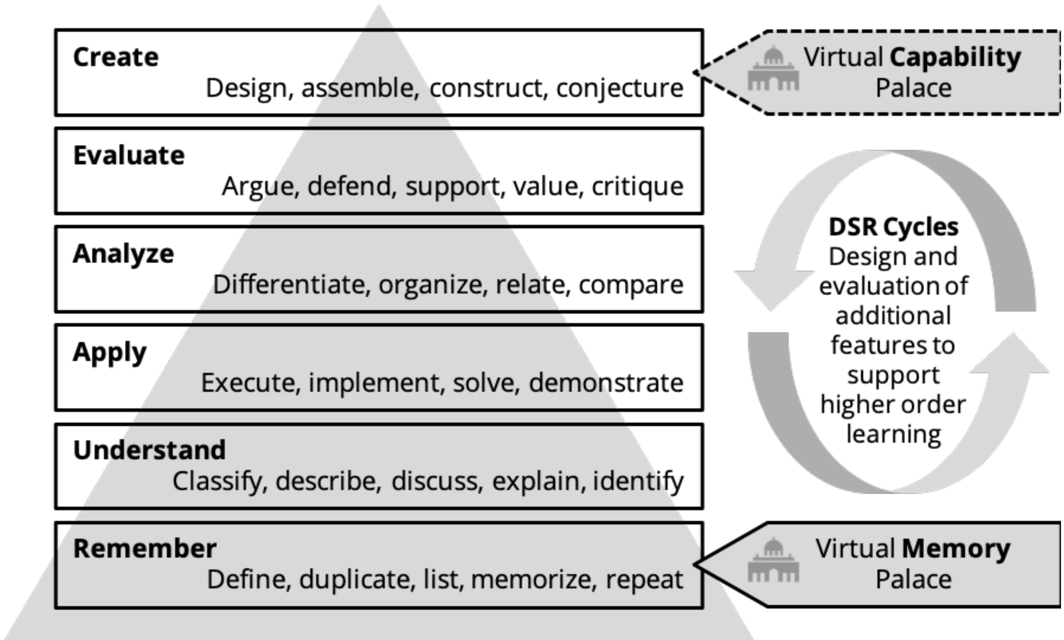


Figure 8.1: From a Memory Palace to a Capability Palace

8.2 Conclusion

The findings of this thesis and the ones of the colleagues, open up several challenges for the future. The first scientific paper which implemented and evaluated the underlying idea of a VMP was published in 2000 (Hedman and Bäckström, 2000), nevertheless, the younger publications still deal with basic questions like how to design a VMP (Peeters and Segundo-Ortin, 2019). Since the design of a VMP plays a central role to facilitate the users' memorization and therefore learning process, developers of this concept will have to carefully orchestrate the different design options along with the actual learning content. Further research is obligatory to push the VMP concept to a satisfying level of maturity.

However, considering the current trends, not only technological ones like mixed reality and artificial intelligence, but also educational developments like self-determined and flexible learning methods, it becomes clear, that the concept of a VMP or later a VCP may grow to be a powerful and useful tool. Especially in a critical situation like the ongoing Covid-19 pandemic, where one and a half billion students worldwide are forced to cope with homeschooling (Suhr, 2020), new and promising concepts that support auto-didactic approaches are essential to achieve educational goals (Kufi et al., 2020; Yulia, 2020).

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Appendices

Appendix A: List of Publications citing the Author's Work[1]

- Leyer, M., Brown, R., Aysolmaz, B., Vanderfeesten, I., & Turetken, O. (2019, June). 3D virtual world BPM training systems: process gateway experimental results. In International Conference on Advanced Information Systems Engineering (pp. 415-429). Springer, Cham.

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[1]Excluding self-citations and referred to all VMP related publications of the author, not just the four contained in this thesis.

Appendix B: Analysis Matrix of the Literature Review

Authors	Year	Outlet	ype of the Stud	City	Domain/Discipline*	Technology	User	Degree of Visualization	Palace	Loci	View	Instr. MOL	Subject	Evaluation	N
Hedman & Bäckström	2000	Conference	Full Paper	Stockholm, Sweden	IS Science	Projector	Students	Palace, loci	Fictional environment with museum-like architecture	Text, images, 3D objects	1st person view	no	Exhibition of philosophers quotes	Experiment	10
Börner	2001	Conference	Research in Progress	Bloomington, Indiana, USA	Computer Science	Desktop PC	–	Palace, loci, user	Artificial world, space like appearance	Text, images	3rd person view	–	Image database	–	–
Harman	2001	Conference	Research in Progress	New York City, State of New York, USA	IS Science	PDA	Students	Palace, loci	Blueprints of a building	Hyperlinked text	Bird's-eye view	–	User generated text	–	–
Fassbender and Heider	2006	Journal	Research in Progress	Sydney, Australia	IS Science	Desktop PC	Students	Palace, loci	Castle	Symbols and Pictures with interactive features	1st person view	yes	Random image content	Experiment	15
Losh	2006	Conference	Full Paper	Irvine, California, USA	Media Studies	Desktop (Tactical Iraqi) & VR (Virtual Iraq)	Soldiers	Palace, loci, user	Middle-east looking environment	Conversational situations (iraqi citizens)	1st and 3rd person	–	Social behaviour training and post traumatic therapy	–	–
Ikei et al.	2007	Conference	Full Paper	Tokyo, Japan	Computer Science	AR	Students	Loci	Real environment	Real objects plus Images	1st person view	no	Memorization of places	Experiment	6
Foley	2010	Conference	Research in Progress	London, UK	Business and Management	Desktop PC	Students	Palaces on islands in a meta-Palace	City of Venice	–	–	–	Concepts of resereach approaches	–	–
Legge et al. (& Ng et al. 2010)	2012	journal	Full Paper	Alberta, Canada	Psychology	Desktop PC	Students	Palace	Warehouse, apartment, school	–	1st person view	yes	Highly imageable words	Experiment	142

Authors	Year	Outlet	ype of the Stud	City	Domain/Discipline*	Technology	User	Degree of Visualization	Palace	Loci	View	Instr. MOL	Subject	Evaluation	N
Morel et al.	2015	Conference	Research in Progress	Leuven, Belgium	Community Service Engineering	AR for tablets & Beacons	Patients with dementia	Loci	Private homes	beacon + images and info in the app	1st person view	no	Personal memories	Case Study	2
Jund et al.	2016	Conference	Full Paper	Strasbourg, France	Computer Science	Desktop (3D TV)	Students	Palace, loci	Virtual Appartment	images	fixed 1st person vs. Navigation as 1st person due to RQ	yes	Abstract images	Experiment	22
Rosello et al.	2016	Conference	Research in Progress	Cambridge, Massachusetts, USA	Architecture Design, Electrical Engineering, Computer Science	AR	Students	Loci	Real environment	List of terms	1st person view	no	Sports teams	Experiment	14
Irie et al.	2017	Conference	Research in Progress	Tokyo, Japan	Computer Science	AR	Students	Loci fiducials	Real environment	QR Codes as markers for fiducials	1st person view	no	Memorization strategies, gaming completion, memorization performance	Experiment	27
Mann et al.	2017	Conference	Research in Progress	Blacksburg, Virginia, USA	Biomedicine	Desktop PC & CAVE	Students	Palace, loci	Campus environment	3D with text	1st person view	no	List of words	Experiment	37
Ralby and Mentzelopoulos	2017	Conference	Research in Progress	Ithaca, State of New York, USA	Linguistic & Computer Science	VR	Children with dyslexia	Palace, loci	Void area with pedestals	Self selected images and descriptions	1st person view	yes	Languages	Case Study	20
Yamada et al.	2017	Conference	Research in Progress	Tokyo, Japan	Computer Science	AR	Students	Loci fiducials	Real environment	QR Codes as markers for fiducials	1st person view	no	Memorization strategies, Gaming completion, Memorization performance	Experiment & Design Workshop	23
Caluya et al.	2018	Conference	Full Paper	Takayama, Ikoma, Nara	IS Science	VR & AR	Trainees of workers	Palace, loci	Spatial Map representing a scheme of a technological interface/ control panel (see Figure).	Displays and buttons, description of the loci close to the target, salient backgrounds	Kind of bird's-eye view	no	Technological interface representing general work space interfaces	Experiment	16

Authors	Year	Outlet	ype of the Stud	City	Domain/Discipline*	Technology	User	Degree of Visualization	Palace	Loci	View	Instr. MOL	Subject	Evaluation	N
Csapó et al.	2018	Conference	Full Paper	Budapest, Hungary	Computer Science	VR	–	Palace, loci	Artificial world, space like appearance	Pictures of handwritten notes	1st person view	–	Screenshots of diagrams, images of handwritten notes	Theory-driven design	–
Hagström and Winman	2018	Journal	Full Paper	Uppsala, Sweden	Psychology	Desktop PC	Students	Palace, loci	Appartement buildung, farmhouse, villa	Loci in 3D as objects in the environment plus displaying the german articles on the top of the screen	1st person view	yes	German articles	Experiment	48
Vindenes et al.	2018	Conference	Research in Progress	Bergen, Norway	Computer Science	VR	Students	Palace, loci	Low detailed virtual environment	List of terms as 3D cubes with images	1st person view	yes	Random content	Experiment	18
Caplan et al.	2019	Journal	Full Paper	Edmonton, Alberta, Canada	Psychology	Desktop PC	Students	Palace	Three different virtual environments (apartement, open space, radial arm architectue)	Imaginary	1st person view	yes	Five lists of generic terms	Experiment	173
Das et al.	2019	Conference	Full Paper	Atlanta, Georgia, USA	IS Science	Smartphone	Students	Palace	Hallways and doors, based on a random algorithm that shuffles tetris blocks	Paths	1st person view	no	VMP as authentification mechanism: specific route needed to pass authentification	Experiment	34
Huynh et al.	2019	Conference	Research in Progress	Santa Barbara, California, USA	IS Science	AR	Students	Loci	Real environment	Real objects plus labels	1st person view	no	Language learning	Theory-driven design	3
Krokos et al.	2019	journal	Full Paper	Washington, D.C., District of Columbia, USA	Computer Science	Desktop PC & VR	Students	Palace, loci	Medieval town	Images	1st person view	yes	Peoples faces	Experiment	40

Authors	Year	Outlet	ype of the Stud	City	Domain/Discipline*	Technology	User	Degree of Visualization	Palace	Loci	View	Instr. MOL	Subject	Evaluation	N
Leyer et al.	2019	Conference	Full Paper	Rostock, Germany	IS Science	Desktop PC	Students	Palace, loci, user	Office	Desks with symbols and descriptions	3rd person view	no	Business process activities and gateways	Experiment	145
Liu et al.	2019	Conference	Research in Progress	Durham, North Carolina, USA	Computational Media & Arts	VR	Students	Palace, loci	Five generic rooms	3D, rotating and pickable	1st person view	yes	Casual objects	Experiment	14
O'Grady and Yildirim	2019	Conference	Full Paper	Oswego, State of New York, USA	Cognitive Science	VR	Students	Palace, loci	Restaurant, apartment, classroom	images with text	1st person view	yes	List of words	Experiment	28
Peeters and Segundo-Ortin	2019	Journal	Research in Progress	Wollongong, New South Wales, Australia	Cognitive Science	VR	–	–	–	–	–	–	–	Theory-driven design	–
Raso et al.	2019	Conference	Research in Progress	Saarbrücken, Germany	IS Science	AR	Students	Loci	Real environment	Text labels	1st person view	no	Topic Clusters of references of scientific papers	Experiment	40
Reggente et al.	2019	Journal	Full Paper	Santa Monica, California, USA	Neuroscience	Desktop PC	Students	Palace, loci	"Toon World," Ruin World," "Lagoon World," "Moon World," and "Avatar Island"	3D with text, self-selected position	1st person view	yes	Random content	Experiment	60
Gelsomini et al.	2020	Journal	Research in Progress	Shizuoka, Japan	IS Science	AR	Students	Loci	Real environment	Logographics	1st person view	–	Text and image. Content is automatically generated and placed based on semantic aspects	–	–